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EFFECT OF DILUTION ON THE pH OF SOILS TREATED WITH VARIOUS CATIONS

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There has been much discussion as to the ratio of soil water that should be used in determining hydrogen-ion concentrations. In a recent publication (11) the International Society of Soil Science recommends for experimental work a soil water ratio of 1:2.5. For mineral soils Snyder (13) recommends a ratio of 1:2. Billmann and Jensen (3) in working with Danish mineral soils used a ratio of 1:1. Barnette, Hissink, and Van Der Spek (2) recommend the thicker suspensions as showing a more constant hydrogen-ion concentration. There are many other publications on this subject and most of them recommend a low soil-water ratio. Snyder (13) has satisfactorily reviewed the literature on this subject. The consensus is that small amounts of water are to be desired.

THE PROBLEM

The authors of the present paper, bearing in mind the base-exchange and electrodialysis work of Gedroiz (5), Hissink (8), Kelley (9), Mattson (10), and Bradfield (4), decided to determine the effect of dilution upon the reactions of soils when they contained various cations. The basic ions selected for use were those more commonly found in soils and were H^+, NH_4^+, Na^+, K^+, Ca^{++}, Mg^{++}, Al^{+++}, and Fe^{+++}. The quinhydrone electrode was used in making the determinations.

SOILS USED

Six surface soils were chosen for the investigation. These soils had previously been used in base-exchange studies by Sewell and Perkins (12), and were selected as being representative of the locality in which they are found. The samples were collected in eastern Kansas, where the rainfall is between 30 and 40 inches a year, and the range in temperature varies approximately from −20°C. to 38°C., although the extreme temperatures will be somewhat beyond these figures. The soils are mineral in nature and are somewhat acid, having been leached free from exchangeable sodium, and in most of them the iron has started to collect in concretions. The exchangeable base content of these soils, as obtained from the field, was determined by Perkins (12) and is shown in table 1. The methods for exchangeable bases are those of Gedroiz (6, 7).

[1] Contribution no. 154, department of chemistry.

Since it was desirable to work with small samples, it was decided to use only the finer portions of the soil. These portions were separated by sedimentation after the soil was saturated with sodium by double exchange, normal sodium chloride being used. The fraction used was that fraction which, when freed from soluble chlorides, would remain in suspension in a 24-inch column of water for 24 hours, containing the particles of smaller diameter than 0.005 mm. By this method approximately 20 per cent of the soil was separated for use. This point of division was selected, as tests on these soils indicated that particles of this size and smaller contained almost all of the base-exchange complex. The larger particles, having but a trace of exchange capacity, were regarded as inactive, and were discarded. The use of only the finer particles facilitated the obtaining of small, uniform samples.

TABLE 1

Bases extracted by 0.05 N *HCl, hydrogen by* N $BaCl_2$, *and pH of soils studied*

SOIL NUMBER	SOIL TYPE AND SOURCE	pH, MOIST SOIL	EXTRACTED BASES IN M.EQ. PER 100 GM.					
			H	Al	Fe	Ca	Mg	K
1	Summit, Ft. Scott, Bourbon County	5.46	2.2	27	9.0	120	92	2
2	Cherokee, Columbus, Cherokee County	4.78	9.2	62	3.7	48	30	2
6	Boone, Halls Summit, Coffee County	5.66	?	21	4.3	94	89	4
8	Oswego, Moran, Allen County	5.46	7.2	53	1.3	63	31	2
11	Oswego, Manhattan, Riley County	?	?	18	1.0	187	24	1
12	Derby, Manhattan, Riley County	?	?	70	2.3	244	47	2

PREPARATION OF SAMPLES

The finer fractions of the soil as separated contained sodium as their exchangeable base. These fractions were treated with the chlorides of various bases. The soils were treated with normal chloride solutions of potassium, ammonium, calcium, magnesium, iron (ferric), and aluminum, and 0.05 *N* Hcl. These treatments were made by shaking approximately 20 gm. of soil with 500 cc. of the chloride solution in centrifuge bottles. After thorough mixing was achieved the soil was packed by centrifuging and the supernatant liquid was poured off. The electrolitic solution withdrawn was replaced and the process repeated until after equilibrium was reached. In testing for equilibrium, determinations were made of the ammonium concentration in the ammonium chloride solution before and after being mixed with the soil. Ammonium was selected, as its energy of adsorption is less than that of the other bases, except potassium, and its determination is simple. The strength of the hydrochloric

acid was also determined by titration. After equilibrium was judged to be complete the chloride solutions were added twice more to take care of the low adsorption energy of potassium. All the soils were treated 12 times to replace the sodium with the other base. The soils were then repeatedly washed with water until the soluble chlorides were removed or reduced to such a low concentration that sedimentation aided by centrifuging would not occur rapidly. By washing with water alone, the soils treated with iron and aluminum were completely freed from soluble chlorides. The soils that had been treated with sodium, potassium, ammonium, hydrogen, calcium, and magnesium, after being washed with water were then washed with 95 per cent alcohol. By the alcoholic washings the calcium, magnesium, hydrogen, and ammonium soils were entirely freed from soluble chlorides. The sodium and potassium soils were nearly freed from soluble chlorides by alcoholic washing, judged by the fact that the last wash solution recovered before sedimentation failed to occur contained only several parts of chloride per million.

The soils treated as previously described were not saturated to the same degree with the various bases, as the chloride solutions were not neutralized. Neutralization of ferric and aluminum chloride would precipitate the cation, and to keep the series uniform the other solutions were not neutralized. The degree of saturation therefore would depend on the ratio of the energy of adsorption for the base and hydrogen, and on the amount of hydrogen present as a result of hydrolysis.

In washing the soils free from chlorides there was also opportunity for hydrolysis to take place, replacing some of the base with hydrogen. Analyses of the samples in which the total bases were determined indicated that the soils treated with aluminum chloride had absorbed only a trace of the base. Smaller quantities of the magnesium than of the other bases were adsorbed. Enough base was adsorbed in every case to have a decided effect on the physical characteristics of the soil. The aluminum-treated soil for instance had a noticeably low specific gravity, whereas the iron-treated soil had an intense red color.

DATA COLLECTED

The pH values presented in tables 2 to 9 were determined after the soils had been air-dried for approximately six months. The quinhydrone electrode was used in making these determinations, and the potentials were read about 30 seconds after the soil, water, and quinhydrone had been mixed. The soil-water ratios used were 1:1, 1:2.5, 1:10, and 1:100 and data are presented for these mixtures. A few determinations were made using other ratios and these indicated that the curves obtained were regular. In figure 1 the pH values shown are the average values for the six soils and the curves are drawn from the four points only, as indicated. The results given are reproducible under standard conditions, but there is considerable variation in the figures obtainable as drying progresses. When freshly prepared the soils treated with ferric

chloride did not show a greater degree of acidity at the 1:100 dilution than the hydrogen chloride-treated soils. The aluminum chloride-treated soils showed great variation in degree of acidity, especially in the greater dilutions. When

TABLE 2

pH values of HCl-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	2.80	2.80	3.17	2.97	3.33	3.30	3.06
1:2.5	3.15	3.15	3.47	3.27	3.45	3.45	3.32
1:10	3.15	3.25	3.52	3.38	3.47	3.54	3.39
1:100	3.65	3.52	3.82	3.80	3.96	3.75	3.75

TABLE 3

pH values of $FeCl_3$-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	2.97	3.03	3.11	3.14	3.18	3.18	3.10
1:2.5	3.36	3.38	3.36	3.41	3.34	3.34	3.36
1:10	3.43	3.41	3.38	3.36	3.36	3.31	3.38
1:100	3.63	3.53	3.58	3.58	3.61	3.61	3.59

TABLE 4

pH values of $AlCl_3$-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	4.16	4.36	4.16	4.23	4.06	4.20	4.19
1:2.5	4.56	4.56	4.16	4.38	4.10	4.40	4.36
1:10	4.36	4.50	4.10	4.50	4.13	4.50	4.34
1:100	4.70	4.80	4.70	4.83	4.53	4.79	4.72

TABLE 5

pH values of NH_4Cl-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	5.63	5.56	5.66	5.61	5.56	5.56	5.59
1:2.5	5.75	5.75	6.01	5.65	5.86	5.82	5.81
1:10	6.42	6.52	6.56	6.22	6.46	5.96	6.36
1:100	6.69	6.77	6.65	6.62	6.82	6.42	6.66

freshly prepared soil was used the aluminum soils were more acid at the 1:100 dilution than at the 1:1 dilution. The indication of these variations is that even though the soils are air-dry they are not in equilibrium.

TABLE 6

pH values of $MgCl_2$-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	6.36	6.22	6.32	6.19	6.32	6.32	6.29
1:2.5	6.36	6.42	6.49	6.36	6.59	6.59	6.47
1:10	6.62	6.75	6.82	6.57	6.92	6.80	6.75
1:100	6.56	6.69	6.75	6.56	6.82	6.75	6.69

TABLE 7

pH values of $CaCl_2$-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	6.49	6.56	6.19	6.29	6.61	6.36	6.42
1:2.5	6.69	6.95	6.46	6.72	6.79	6.56	6.69
1:10	6.95	7.29	6.75	7.12	7.02	6.89	7.00
1:100	6.92	7.22	6.74	7.05	7.02	7.09	7.01

TABLE 8

pH values of KCl-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	6.72	6.72	6.82	6.75	6.68	6.78	6.74
1:2.5	6.80	6.85	7.05	6.78	7.07	7.25	6.97
1:10	7.30	7.40	7.58	7.43	7.72	7.78	7.54
1:100	7.72	7.68	7.58	7.55	7.78	7.92	7.71

TABLE 9

pH values of NaCl-treated soils

SOIL-WATER RATIO	SOIL NUMBERS						
	1	2	6	8	11	12	Average
1:1	6.68	6.72	6.85	6.75	6.92	6.98	6.82
1:2.5	6.98	6.92	7.02	6.88	7.15	7.32	7.04
1:10	7.68	7.58	7.85	7.65	7.99	8.02	7.80
1:100	7.78	7.75	8.02	7.72	8.22	7.95	7.92

DISCUSSION

From the data presented it may be judged that regardless of the base adsorbed by the soil the effect of dilution on soil reaction is similar. In the graph it may be noted that moderate dilution tends to increase alkalinity. It is also considered that a ratio of 1:2.5 is satisfactory for making pH determinations. A smaller amount of water with many soils gives a viscous paste that is hard to bring into intimate contact with the electrode, and a larger amount of water departs further from natural soil conditions.

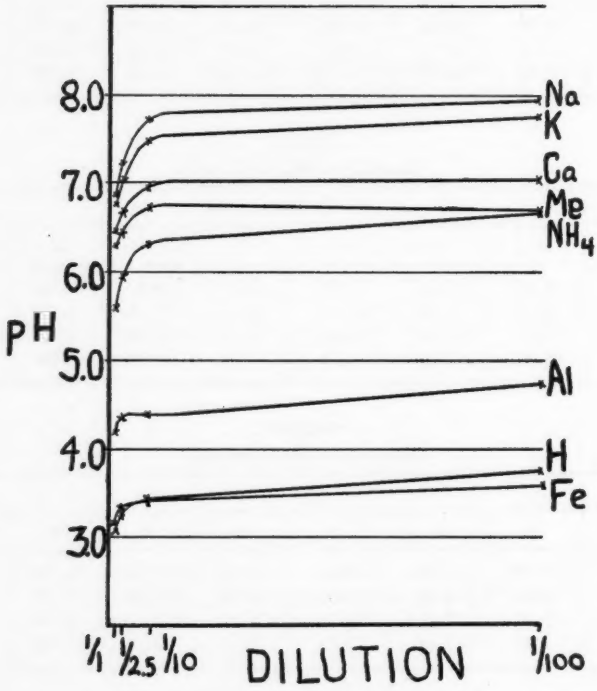

FIG. 1. pH VALUES AT SEVERAL SOIL-WATER RATIOS
Averages for six soils

It will be noted that maximum difference in pH values for dilution of 1:1 and 1:100 is 1.10 in the case of sodium and 0.40 in the case of magnesium. It will also be noted from the graph that regardless of base the curves between the dilutions of 1:1 and 1:2.5 are nearly vertical, and that between the dilutions of 1:10 and 1:100 are nearly horizontal.

The observations should be made that the soils treated with aluminum chloride have a low specific gravity and a high water holding capacity. In these

soils at the 1:1 dilution a thick paste was made that was hard to bring into contact with the electrode. The soils treated with other bases were much more fluid at this concentration.

As pH determinations were made on these soils from time to time it was noted that they became more acid as drying progressed. Work has started to bring portions of these soils into a state of dryness obtainable by storing them in a desiccator over calcium chloride. Other portions have been stored in desiccators over water. Preliminary work has indicated that it will take about a year before these soils reach approximate equilibrium. When stability is obtained, with the recent publication of the International Society of Soil Science (11) in mind, new determinations will be made to find the effect of base adsorbed and degree of hydration on pH value and potential drift. Preliminary work indicates the possibility that the hydrolysis constant of the base associated with degree of dilution might have some effect on potential drift.

SUMMARY AND CONCLUSIONS[2]

Selected soils were treated with various bases and the pH values determined at several degrees of dilution.

It is found in working with eastern Kansas mineral soils that dilution tends to give a more alkaline reaction.

Regardless of the adsorbed base present in a soil, degree of dilution has about the same effect on the soil reaction.

A dilution of 1:2.5 is satisfactory for determining soil reaction.

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[2] *Note during printing:* Since the present article has been prepared for publication the abstract of the article by Aarnio (1) has been noted. Although the results presented here are not in complete accord with Aarnio's it is hoped that future work will explain these differences.

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A METHOD FOR THE STUDY OF AZOTOBACTER AND ITS APPLICATION TO FERTILITY PLOT SOILS[1]

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Received for publication October 1, 1930

A great many investigations have been conducted on the physiology of the nitrogen fixing bacteria but few have been made on the effect of environmental conditions in the soil on these microorganisms. The object of the work reported in this paper has been to develop a method for comparing the Azotobacter flora in different soils, and to study the effects of various fertilizer treatments on the Azotobacter flora in fertility plot soils.

INTRODUCTION

Until very recently all studies on Azotobacter have been based on either the soil incubation method or the solution method.

The soil incubation method

A quantity of soil, usually 100 gm., is mixed with 1 or 2 per cent of mannite and placed in a tumbler or soup plate. Sufficient water is added to establish optimum moisture conditions. The soil is incubated for three or four weeks at a temperature of 25 to 28°C. The nitrogen content of the incubated soil and of the original soil is then determined. The difference between the nitrogen content of the incubated soil and that of the original soil represents the amount of nitrogen fixed.

The solution method

The culture solution contains a carbohydrate, nutrient salts, and an excess of calcium carbonate, but is deficient in nitrogen. Measured 50- or 100-cc. portions of this solution are put into 250-cc. Erlenmeyer flasks. The flasks of medium are sterilized and then inoculated with 5 or 10 gm. of the soil to be studied. Examinations for the typical brown Azotobacter film are made at

[1] Part of a thesis presented to the graduate faculty of Ohio State University in partial fulfillment of the requirements for the degree of master of science. This investigation constitutes one part of a general project on nitrogen fixation being conducted in the soil biology division of the agronomy department at the Ohio Agricultural Experiment Station.

[2] The writer wishes to express sincere appreciation to Mr. H. W. Batchelor, under whose direction this investigation was conducted. Thanks are due also to Prof. Robt. M. Salter for his kind suggestions and criticisms.

intervals of a few days. The solutions are incubated for a total period of three or four weeks at 25 to 28°C. At the end of the incubation period total nitrogen determinations are made on the incubated cultures, on the control solution, and on the soil. The amount of nitrogen fixed is the difference between the nitrogen contained in incubated culture and that contained in the soil and the control solution.

The Winogradsky method

In 1926 Winogradsky (9) described a new method by which soils could be classified according to their Azotobacter flora. The method includes the five determinations listed below.

1. Silica gel plates, 9 cm. in diameter, are inoculated with 50 soil granules each. After 48 hours colonies develop about the granules which contain viable Azotobacter cells.
2. One-half gram of mannite is mixed with 50 gm. of moist soil. A microscopic examination is made after 48 hours' incubation.
3. Five per cent of starch is mixed with moist soil and the soil is molded into Petri dishes. The colonies which appear on the smooth surface of the soil are counted after 48 hours' incubation.
4. Silica gel plates, 20 cm. in diameter, are inoculated with 1 gm. of soil. The colonies appearing on the plates are counted after 48 hours' incubation.
5. The nitrogen fixed on the 20-cm. plates is determined after 5 days' incubation.

Limitations of these methods

The soil incubation method is unsatisfactory because the quantities of nitrogen fixed are usually too small to permit significant comparisons to be made. Any toxic substances produced during incubation accumulate and may retard Azotobacter activity before the end of the incubation period. Azotobacter is forced to compete with many other organisms for the carbohydrate provided. The method is not comparable to field conditions since the addition of 2 gm. of mannite to 100 gm. of soil is equal to a field application of 20 tons an acre. Such a large amount of available carbohydrate is never present under field conditions. Consequently, the rate of fixation under field conditions cannot be expected to compare with that obtained by this method.

There are a number of objections to the use of the solution method. With this method aerobic conditions are found only at the surface of the culture solution. Butyric acid is frequently formed during incubation and may retard or stop Azotobacter development. Azotobacter is forced to compete with other organisms for the mannite, and in addition, amoebae flourish in the solution and may devour many Azotobacter cells. It is very probable that a film is produced only when there are many Azotobacter cells present (3, 9).

Either the soil incubation method or the solution method thus provides a qualitative test for the presence or absence of Azotobacter, but neither provides for an estimation of the number present or a quantitative measure of their activity. The results obtained may depend as much on the variable factors in the methods as on the number or activity of the Azotobacter present.

No reports on the Winogradsky method were available when this project was begun in October, 1926. It appeared that it should be possible to make quantitative comparisons by this method. For this reason it was selected for further study.

EXPERIMENTAL

Laboratory studies were made on the five determinations included in the Winogradsky method. The first three of these determinations permit only superficial comparisons of the flora in different soils. They are essentially qualitative in nature and were found unsatisfactory for this investigation. The fourth and fifth include a determination of the number of Azotobacter colonies in the soil and a determination of the amount of nitrogen fixed under controlled conditions. Work was confined to these latter determinations since it was felt that only these would permit quantitative comparisons of the Azotobacter flora in different soils.

A detailed description of Winogradsky's procedure for these determinations follows.

Silica gel is used as a base for the medium in this determination and is prepared as follows:

Dilute hydrochloric acid; specific gravity 1.10, and potassium silicate solution, specific gravity 1.06, are mixed in equal volumes by pouring the silicate solution into the acid and shaking well. This mixture is distributed immediately into 20-cm. Petri dishes at the rate of 200 cc. per dish. The layer of gel should be more rather than less than $\frac{1}{2}$ cm. in thickness. The dishes are left undisturbed on a level surface for at least 24 hours. The gel is sufficiently solid when distinct vibrations are felt if the dish is tapped with the hand. This indicates that the gel is sufficiently elastic and tough to undergo the subsequent treatment without being disrupted. The plates of gel are washed in running water for two or three days and finally with boiling distilled water by flooding the surface of the plates several times. This wash water should give a distinct violet reaction with brom-cresol-purple and should give no turbidity with silver nitrate. The dishes thus prepared may be kept in stock for a long time if they are protected from dessication.

The following stock solution is prepared:

Di-potassium phosphate	0.5 gm.
Magnesium sulfate	0.3 gm.
Sodium chloride	0.3 gm.
Ferric sulfate	Trace
Manganese sulfate	Trace
Distilled water	100 cc.

To prepare a nutrient plate, 10 cc. of this solution, 2 gm. of mannite, and 0.5 – 0.7 gm. of calcium carbonate are placed in a small flask, heated to boiling, and poured over the surface of the gel. The open plate is then dried at a temperature of 40 to 50°C. for several hours or until the surface liquid has evaporated. In order to prevent cracking of the gel the drying is discontinued as soon as the surface of the gel appears dry.

A representative sample of soil is collected from the plot to be studied. This sample should be a composite of a large number of borings taken at equal distances over the surface of the whole plot. This composite sample is carefully mixed and passed through a sterile 20-mesh sieve. About 12 gm. of the moist, sifted sample is used to determine moisture content by drying for two hours at 100°C. In the meantime the remainder of the sample is protected from drying. After the moisture content has been determined, the proper amount of moist soil to equal 1 gm. of dry soil is weighed out. This sample of moist soil is scattered uniformly over the surface of the gel.

The Azotobacter colonies may be recognized at the end of 48 hours' incubation at 28 to 30°C. In diameter and in thickness they form the only important growth on the plates. The number of colonies which have developed at this time are counted and are considered to represent the number of Azotobacter colonies per gram of soil. The nitrogen fixing activity of these bacteria may be determined on these same plates. For this purpose the incubation is continued to a total period of five days. At the end of this time the plates are dried at a gentle heat (40 to 50°C.) until the gel becomes a mass of dry, brown scales. The dried gel and the bacterial growth are then transferred to a Kjeldahl flask and the total nitrogen is determined. It is also necessary to determine the nitrogen content of a plate of uninoculated gel and of 1 gm. of the dry soil inoculum. The amount of nitrogen fixed is determined by difference.

This procedure may be criticized because the medium is not sterilized and because difficulty might be anticipated in identifying the Azotobacter colonies in the heterogeneous flora appearing on the plates. These criticisms are unwarranted. The medium is so sharply selective that in appearance the plates frequently suggest a pure culture. In each case the Azotobacter colonies stand out so sharply that they may be recognized by their macroscopic appearance alone. A microscopic examination impresses one with their uniformity and purity. It should be noted that the number of colonies which develop on the plates may not and probably does not correspond to the number of cells in a gram of soil since Azotobacter is found in the soil in the state of natural colonies. Consequently the number of viable colonies, which is probably much less than the number of cells, will determine the number of colonies that appear on the plates. This procedure is simple and rapid. Although it is not a pure culture method of study, it has produced remarkably constant results.

Development of the agar plate method

Soils from several plots of the Ohio Agricultural Experiment Station farm at Wooster were used in a preliminary study of the silica gel plate method. In general the results obtained were satisfactory. The soil remained on the surface and absorbed water from the gel. Aerobic conditions and yet an adequate supply of moisture were thus assured. The medium was found to be very selective and permitted the growth of typical and practically pure cultures of Azotobacter. No appreciable growth of other organisms was found

about the soil granules which did not produce Azotobacter colonies. Distinct differences were found between the different plot soils, the nitrogen fixed having varied from 0 to 17 mgm. per plate. The results were sufficiently uniform to permit a quantitative comparison of the Azotobacter flora of different soils.

Use of soil granules.—One objection to the Winogradsky method which early became evident is the type of inoculum used for the plates. The inoculum consists of soil which has been passed through a 20-mesh sieve. A great variation in the size and number of the soil granules is possible with such a soil sample. It was considered advisable to obtain a sample of granules more uniform in size. This has been done by passing the soil sample through two sieves, a 20-mesh sieve and a 40-mesh sieve. The soil granules which pass through the former but are retained on the latter are used as an inoculum. This restriction of the size of the soil granules has resulted in more uniform colony counts. A few counts of the soil granules per gram of soil from the different plots have been made. Although some variation in the number has been found, the differences have not been sufficiently great to account for the variation in the Azotobacter flora of the plots.

It is realized that an arbitrary standard has been set in the use of these granules but the uniform and consistent counts obtained have apparently justified its use on this particular soil type.

Use of agar.—The most serious objection to the method is due to the variation in the moisture content of the gel of different plates. Since the excess water is evaporated from the gel until the surface appears dry, the moisture content of different plates may vary considerably. On plates having a relatively low moisture content the colonies are somewhat viscous and maintain their identity. A high moisture content results in liquid colonies that have a marked tendency to coalesce. In the latter case they may spread until the growth covers the entire surface of the plate. The coalesence of the colonies makes a count difficult or impossible and causes considerable variation in the amount of nitrogen fixed. The length of time required to complete an analysis is another undesirable feature of the method. Approximately 10 days are required from the time the gel is prepared until the nitrogen analyses are completed.

In an effort to prevent the coalescence of colonies 1½ per cent agar was substituted for the silica gel medium. In general this change has been very satisfactory. The preparation of the plates is more simple and much quicker since the medium may be prepared and the plates inoculated in a few hours' time. The colonies do not develop as rapidly on the agar medium as on the silica gel. Consequently, an incubation period of three or four days at 28°C. is necessary to develop the maximum number of colonies. The more uniform water content of the agar as compared with the silica gel results in a marked reduction of the tendency of the colonies to coalesce. Thus, more uniform results are obtained, both in colony counts and in nitrogen fixation. The agar medium is slightly less selective than the silica gel, but the Azotobacter colonies

are easily distinguished from the few other types which occasionally appear on the plates.

Selection of nutrients.—Attempts were made to replace mannite with a less expensive source of energy. The Azotobacter colony count remained practically the same when mannite, dextrose, or dextrin was used. A medium prepared with either dextrose or dextrin, however, was found to be much less selective than the mannite medium. The use of mannite has been continued because it is difficult to identify the Azotobacter colonies when using dextrose or dextrin.

The stock solution used by Winogradsky is quickly contaminated by molds so it has been replaced by a dry stock salt mixture. The following proportions of salts are ground to pass a 40-mesh sieve, thoroughly mixed, and stored in a glass-stoppered jar until used.

	Parts
Di-potassium phosphate	100
Magnesium sulfate	60
Sodium chloride	60
Ferric sulfate	1
Manganese sulfate	1
Calcium carbonate	178

Two grams of this mixture is used for each liter of medium.

Use of aluminum dishes.—The 20-cm. glass Petri dishes used in this procedure are rather unsatisfactory. They are clumsy and heavy to handle in quantities. Dishes of the grade usually available have irregular bottoms. For this reason it is necessary to use a large quantity of medium to obtain a sufficiently uniform layer of gel. The glass plates cannot be stacked in the quantities desirable for sterilization or storage. Sterilization and handling of plates cause considerable breakage, and replacements are expensive.

To avoid these undesirable features of the glass Petri dishes, dishes made of aluminum were substituted.[3] The aluminum dishes have proved to be very satisfactory for this type of work. These dishes weigh less than half as much as the glass dishes. They are uniform in shape, have flat tops and bottoms, and may be stacked for sterilization or storage. Satisfactory photographs of single colonies or entire plates can be made from cultures on the aluminum dishes. There is no danger of breakage in sterilization or in other handling, and the original cost is decidedly less than the cost of glass dishes.

Proper incubation period.—The proper incubation period and the number of plates necessary to obtain significant results were determined by the following experiment. Fifty plates were inoculated with a plot soil known to have a relatively low Azotobacter count. These plates were counted after two, three, four, five, and six days' incubation. The results are shown in figure 1. From this figure it is evident that an incubation period of at least three days is

[3] The aluminum petri dishes were made available through the courtesy of The Buckeye Aluminum Company, Wooster, Ohio. They may be obtained by ordering Style No. 8015.

necessary to obtain a significant colony count. The apparent slight decrease in the count after five days' incubation is due to the coalesence of the colonies as they grow larger.

Number of plates required.—The probable error of the plate count was first determined. The count for the foregoing series of 50 plates after four days incubation was found to be 16.6 ± 0.34 colonies per gram, an error of 2.07 per cent (7). The percentage of error for various numbers of plates was then calculated according to the formula

$$Em = \frac{0.6745 \times C.V.}{\sqrt{n}}$$

where Em is the percentage of probable error, $C.V.$ is the coefficient of variability, and n is the number of determinations. The percentage of error is

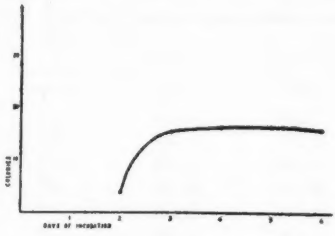

FIG. 1

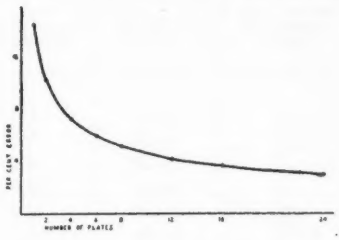

FIG. 2

FIG. 1. RELATION OF INCUBATION PERIOD TO NUMBER OF COLONIES

FIG. 2. RELATION OF NUMBER OF PLATES TO PER CENT ERROR

plotted against the number of plates in figure 2. This graph indicates that the probable error may be maintained within 5 per cent by the use of eight plates for each soil sample. Eight plates have been used in all subsequent work and the differences between the counts for different plots have been found to be significant in practically all cases.

Relation of colony count to nitrogen fixation.—Winogradsky used the 20-cm. plates to determine: first, the number of Azotobacter colonies per gram of soil; and second, the ability of the soil to fix nitrogen. He evidently believed that the determination of the nitrogen fixed would yield information in addition to that given by the colony count. The nitrogen fixed has been found, however, to be a function of the number of colonies per plate. This relation obviates the determination of nitrogen fixation on the plates. For this reason nitrogen determinations have been discontinued in all subsequent work.

To determine this relation, the data obtained from a series of 167 plates were tabulated according to the number of colonies per plate. The nitrogen fixed per colony was then calculated from the nitrogen fixed per plate. The nitrogen fixed per colony appeared to decrease as the number of colonies per

plate increased. To summarize these data they were divided into groups according to the number of colonies per plate as follows: 1–5, 6–10, 11–15, 16–20, etc. The average colony count and the average nitrogen fixation per colony were determined for each of these groups. The values obtained are given in table 1.

The nitrogen fixed per colony plotted against the number of colonies per plate is shown in figure 3. It is evident that the nitrogen fixed per colony decreases as the number of colonies per plate increases, and although the relation is not linear it tends to follow a smooth curve. From the general positions of the points it might be expected that a curve drawn through them would assume the form of a logarithmic curve. To determine the "best" curve that

TABLE 1

Comparison of colony count with nitrogen fixation

NUMBER OF PLATES	COLONIES PER PLATE	AVERAGE NUMBER OF COLONIES	NITROGEN FIXED PER COLONY		ERROR
			Determined	Calculated	
			mgm.	*mgm.*	*per cent*
36	2–5	3.5	0.234	0.242	−3.3
12	6–10	7.5	0.227	0.207	+10.3
7	11–15	13.0	0.203	0.182	+11.5
14	16–20	18.4	0.153	0.166	−7.8
12	21–25	22.8	0.151	0.156	−3.2
10	26–30	28.1	0.138	0.146	−5.5
11	31–35	33.6	0.131	0.138	−5.1
11	36–40	38.0	0.134	0.132	+1.5
13	41–45	43.2	0.153	0.127	+20.5
7	46–50	48.0	0.128	0.122	+4.9
10	51–55	52.5	0.122	0.118	+3.4
6	56–61	57.3	0.116	0.113	+2.7
6	97–132	115.2	0.088	0.081	+8.6
6	147–178	156.0	0.051	0.067	−23.9
6	201–232	218.0	0.047	0.052	−10.4

could be drawn through these experimental points the procedure outlined in the following was carried out.

If the relation were truly logarithmic, one would expect to obtain a straight line if the nitrogen fixed per colony were plotted against the logarithm of the number of colonies per plate. This is shown in figure 4. The equation of the "best" line through these experimental points, determined by the method of least squares, is

$$y = -0.1061 \log x + 0.300$$

where y is the milligrams of nitrogen fixed per colony and x is the number of colonies per plate. With this equation as a basis, the positions of a number of points on the line were calculated. These calculated values are given in

table 1. The "best" line through the points in figure 3 and in figure 4 was drawn from these calculated values. The experimental points are seen to conform closely to this calculated logarithmic curve. Rather than a direct linear relation existing between the nitrogen fixed per colony and the number of colonies per plate, apparently the relation is one in which the nitrogen fixed is an inverse function of the logarithm of the number of colonies per plate. It should be noted that this relation may be expected only if the experimental conditions are maintained within definite limits. These limits have not been determined.

Procedure adopted.—The revised procedure now used is carried out as follows. The medium is made up of 15 gm. of agar, 20 gm. of mannite, and 2 gm. of the stock salt mixture for each liter of medium. This is heated in the autoclave until the agar is completely dissolved. Into each 20-cm. aluminum Petri dish 100 cc. of the medium is poured and allowed to harden. One gram of soil granules that pass a 20-mesh sieve but are retained by a 40-mesh sieve

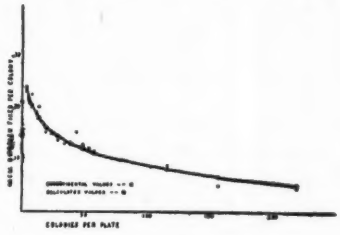

FIG. 3

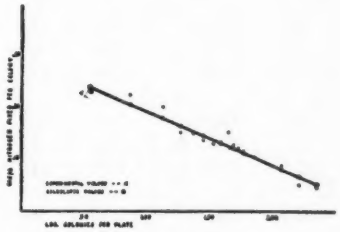

FIG. 4

FIG. 3. RELATION OF COLONY COUNT TO NITROGEN FIXATION

FIG. 4. RELATION OF LOGARITHM OF COLONY COUNT TO NITROGEN FIXATION

is scattered as uniformly as possible over the surface of the agar. Eight plates are inoculated with each soil to be analyzed. After four days' incubation at 28°C. the colonies which have developed on the plates are counted. The average of the counts on the eight plates is taken as the Azotobacter colony count per gram of the soil tested.

Application of the method

The agar plate procedure has been applied to soil samples from the plots of the 5-year rotation fertility experiment at Wooster. The soil on sections C and D of this rotation is Wooster silt loam, a soil formed by the weathering of glacial drift derived largely from sandstone and shale. The surface soil is a brown silt loam which contains some sandstone fragments. This is underlain by a yellowish-brown silt loam only slightly heavier than the surface soil. This soil is acid except where limed, the reaction usually being about pH 5.0. The rotation consists of corn, oats, wheat, clover, and timothy. The plots were laid out in 1893 and have received consistent fertilizer treatment since

that time (6). One end of each plot has received lime at 5-year intervals whereas the other end has never received lime.

TABLE 2

Colony counts for section C

PLOT	TREATMENT	LIMED					UNLIMED	
		pH	Colonies per gram				pH	Colonies
			Spring, 1928	Fall, 1928	Spring, 1929	Average		Spring, 1928
1	Check	7.4	245	145	94	161	5.2	0
2	P	7.4	137	54	38	76	5.0	0
3	K	7.5	108	39	34	60	4.9	0
4	Check	7.6	17	48	43	36	4.9	0
5	N	7.6	156	149	101	135	5.2	0
6	P–N	7.5	90	77	123	97	5.1	0
7	Check	7.4	116	87	102	102	4.9	0
8	P–K	7.4	66	80	50	65	4.8	0
9	K–N	7.4	173	207	136	172	4.9	0
10	Check	7.4	161	101	208	157	5.0	0
11	P–K–N	7.4	79	101	86	89	5.0	0
12	P–K–N	7.3	116	98	30	81	5.1	0
13	Check	7.4	168	168	184	173	4.9	0
14	P–K–N	7.4	162	137	86	128	4.8	0
15	P–K–N	7.3	88	122	71	94	4.9	0
16	Check	7.2	195	76	46	106	5.0	0
17	P–K–N	7.6	23	45	23	30	4.9	0
18	Manure	7.6	66	44	15	42	4.9	0
19	Check	7.5	249	128	158	178	4.9	0
20	Manure	7.4	58	83	35	59	5.0	0
21	P–K–N	7.3	145	99	...	122	4.9	0
22	Check	7.4	194	92	88	125	4.9	0
23	P–K–N	7.2	70	75	...	73	4.9	0
24	P–K–N	7.1	6	18	...	12	4.8	0
25	Check	7.5	456	58	...	256	4.9	0
26	P–K–N	7.5	53	66	...	60	4.9	0
27	P–K–N	7.5	47	37	...	42	4.9	0
28	Check	7.6	169	205	...	187	5.1	0
29	P–K–N	7.6	346	52	...	199	5.2	0
30	P–K–N*	7.7	750	199	...	475	6.0	1

* No treatment since 1921.

The Azotobacter colony counts of the plots of section C and D, determined at different times, and the reactions of the plots in the spring of 1928 are given in tables 2 and 3.

TABLE 3

Colony counts for section D

PLOT	TREATMENT	LIMED						UNLIMED	
		pH	Colonies per gram					pH	Colonies
			Fall, 1927	Spring, 1928	Fall, 1928	Spring, 1929	Average		Spring, 1928
1	Check	7.8	219	243	181	140	196	5.1	0
2	P	7.5	156	115	74	198	136	5.1	0
3	K	7.4	42	27	42	77	47	5.0	0
4	Check	7.4	115	98	67	314	148	5.0	0
5	N	7.6	54	69	46	83	63	5.1	0
6	P–N	7.4	31	32	11	21	24	5.0	0
7	Check	7.4	20	26	37	23	27	4.9	0
8	P–K	7.2	4	4	7	10	6	5.0	0
9	K–N	7.5	31	19	10	21	20	5.0	0
10	Check	7.3	49	90	57	177	93	4.9	0
11	P–K–N	7.3	17	29	16	37	25	5.0	0
12	P–K–N	7.4	20	13	24	34	23	5.1	0
13	Check	7.3	32	15	36	12	24	4.9	0
14	P–K–N	7.2	3	2	4	2	3	5.1	0
15	P–K–N	7.2	1	5	2	1	2	5.2	0
16	Check	7.4	45	51	38	17	38	5.1	0
17	P–K–N	7.5	1	1	25	1	7	5.1	0
18	Manure	7.4	4	2	3	15	6	5.1	0
19	Check	7.6	34	50	56	87	57	5.1	0
20	Manure	7.5	47	60	31	37	44	5.2	0
21	P–K–N	7.4	13	5	11	...	10	5.0	0
22	Check	7.5	41	38	42	66	47	5.0	0
23	P–K–N	7.4	5	8	13	...	9	5.0	0
24	P–K–N	7.3	2	1	3	...	2	4.8	0
25	Check	7.6	20	20	37	...	29	5.0	0
26	P–K–N	7.4	6	12	12	...	10	5.2	0
27	P–K–N	7.5	5	3	15	...	8	5.0	0
28	Check	7.4	31	36	24	...	30	4.9	0
29	P–K–N	7.5	8	3	9	...	7	5.2	0
30	P–K–N*	7.5	54	72	52	...	59	5.0	0

* No treatment since 1921.

Discussion of data for section C.—The average of three series of Azotobacter colony counts on the limed plots of section C is presented in column 7, table 2.

In this table since the check plots are given first in each series a comparison can readily be made between the treated plot counts and their check values. In most cases the counts on the check plots are much greater than the counts on the adjacent treated plots. The average of the counts on the check plots is 177 colonies per gram whereas the average of the counts on the treated plots is only 86 colonies per gram. A statistical analysis shows that the odds are 13,000:1 that the difference between these two averages is not due to chance alone and may be considered significant (5).

Three plots, 5, 6, and 9, in this section have a higher colony count than their respective checks. On referring to the fertilizer treatments on these plots it is observed that each of them receives nitrate of soda, either alone or in combination with superphosphate or muriate of potash. In order to make a

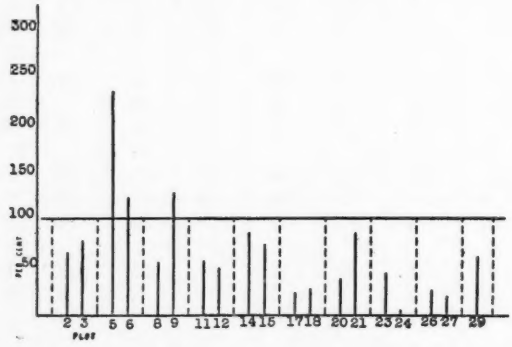

FIG. 5. DATA FOR SECTION C ON CORRECTED CHECK BASIS

further study of these plots the data in column 7 of table 2 have been calculated on a corrected check basis as shown in figure 5.

The check value for each plot has been calculated upon the assumption that the variations in the soils are progressive; that is, if the counts on plots 1 and 4 were 100 and 70 colonies, respectively, then the counts on plots 2 and 3, if left unfertilized, should be 90 and 80, respectively (6). The colony count of each treated plot has been expressed in terms of per cent of its check value in figure 5. The check value is indicated by the line at 100 per cent. The general relation between treated plots and check plots is evident. The average Azotobacter colony count on the treated plots, even including plots 5, 6, and 9 which have exceptionally high counts, amounts to only 67 per cent of the corrected check value. This indicates that, in general, the Azotobacter population has decreased subsequent to fertilizer treatment.

The plots which receive either one or two fertilizer element treatments are of special interest. These are plots 2, 3, 5, 6, 8, and 9. Plot 5 receives applica-

tions of nitrate of soda and the count amounts to 232 per cent of its check value. Thus it appears that nitrate has had a distinct stimulating action on Azotobacter growth. This is in accord with the findings of Hills (4), who reported that Azotobacter was stimulated by small amounts of potassium, sodium, or calcium nitrate.

Plot 2 receives superphosphate and the count amounts to 64 per cent of the check value. Plot 3 receives muriate of potash and the count is 77 per cent of the check value. According to the counts obtained on these two plots it appears that additions of either superphosphate or muriate of potash have been followed by a decrease in the number of Azotobacter colonies. A statistical comparison of the populations on plots 2 and 5 was made and it was found that the odds are 49:1 that plot 5 has the greater Azotobacter population. A similar comparison of plot 3 with plot 5 indicated the odds to be 36:1 that plot 5 has the greater population. From these comparisons it appears that nitrate

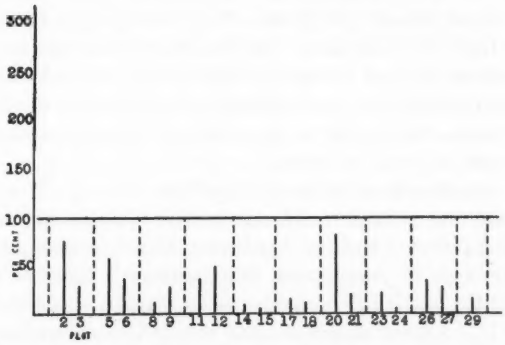

FIG. 6. DATA FOR SECTION D ON CORRECTED CHECK BASIS

of soda is more favorable to the growth of Azotobacter than is either superphosphate or muriate of potash.

In the case of plots 6, 8, and 9, each receives treatments which consist of two fertilizer elements. Plot 6 receives phosphate and nitrate, plot 8 receives phosphate and potash, and plot 9 receives potash and nitrate. Plots 6 and 9 receive nitrate with either phosphate or potash, and each has a count higher than its respective check value. Plot 8 receives phosphate and potash but no nitrate, and has a count of only 54 per cent of its check value. A comparison of plot 6 with plot 8, shows the odds to be 49:1 that plot 6 has a higher Azotobacter count than plot 8. A comparison of plot 9 with plot 8 shows that the odds are 13:1 that plot 9 has a higher count than plot 8.

From a study of the data for these six plots it would appear that additions of nitrate of soda have been followed by an increase in the number of Azotobacter colonies, whereas additions of superphosphate or muriate of potash have been followed by a decrease in the number of Azotobacter colonies.

The treated plots above plot 10 receive complete fertilizer additions and in all cases the Azotobacter count is less than the check value. Another experiment may be mentioned in connection with the foregoing statement. A study was made of the 4-year rotation liming experiment plots at Wooster (6). These plots receive a basic treatment of manure and superphosphate while the form and amount of liming material is varied from plot to plot. The counts obtained on all plots were so low that no significant comparisons could be made. These plots receive complete fertility treatment and therefore the low counts confirm the results obtained on the complete fertilizer and manure plots of sections C and D. It is particularly interesting to note that the counts are low on these plots in spite of the fact that some of them receive as much as 8 tons of lime per acre per rotation.

Discussion of data for section D.—The four series of counts made on section D are summarized in table 3, column 8. The average colony count for the check plots of this section is 68 colonies per gram whereas the average for the treated plots is 24 colonies per gram. No treated plot in this section has a higher count than its check value. In this section it has not been possible to make comparisons between the plots which receive one and two-element fertilizer additions because the counts are abnormally high on the first few plots. These high counts may be due to the effects of a limestone road which runs parallel with and adjacent to plot 1.

Particular attention is called to plot 8 of this section. This plot receives superphosphate and potassium chloride but no nitrogenous fertilizer. The crop producing power of the plot has been maintained at approximately the same level through 35 years under this treatment. Since no nitrogen has been added to the plot it has been cited as an example of the ability of soil to fix nitrogen (1). Approximately one-half of this fixation has been ascribed to symbiotic organisms and the remainder to Azotobacter and related organisms. This plot is well drained, limed, supplied with phosphate, potash, and a fair amount of crop residues, conditions which apparently meet the requirements for abundant Azotobacter growth. In spite of these apparently favorable conditions the Azotobacter colonies are very few, an average of only 6 colonies per gram having been found (see plate 1). This number is so small that Azotobacter cannot be considered as an important factor in the maintenance of the fertility level of this plot.

The summary of the data from section D, calculated on a corrected check basis, is shown in figure 6. Even more distinctly than section C, does this section show a low colony count on the treated plots as compared with the check plots. The average of the colony counts on the treated plots amounts to 39 per cent of the corrected check value.

Discussion of data for check plots.—The variations in the counts on these check plots are wide. In section C the counts vary from 36 colonies per gram on plot 4 to 475 colonies per gram on plot 30. In section D the variation is from 24 colonies per gram on plot 13 to 196 colonies per gram on plot 1. The

counts on the last plots of section C and the first plots of section D are abnormally high as compared with the other plots of the sections. These high counts are apparently due to the effects of a limestone road which separates the two sections, although definite proof of the relation is lacking at the present time. No explanation is offered for variations in other parts of these sections. Obviously these uncontrolled and uncorrelated variations make an accurate interpretation of the results difficult.

An attempt was made to correlate the Azotobacter populations with the crop yields on the check plots by comparing the colony counts with the yields of each of the five crops of the rotation. No definite correlation, either positive or negative, could be demonstrated between the Azotobacter colony counts and the yields of any of the crops grown.

Discussion of data for manure plots.—It is generally believed that additions of manure to soil stimulate Azotobacter growth. This belief has not been substantiated in the data obtained by the agar plate method.

In section C, plot 18 receives 16 tons of manure per rotation and the Azotobacter colony count is 27 per cent of the corrected check value (see plate 1). Plot 20 receives 8 tons of manure and the colony count is 37 per cent of the corrected check value. In section D, plot 18 has a colony count of 12 per cent of its check value, and plot 20 has a count of 82 per cent of the check value. The 4-year rotation liming experiment receives a basic treatment of 8 tons of manure. The colony counts obtained have been so low that no comparisons could be made between different plots.

From the data obtained thus far it appears that manure has resulted in a depression rather than a stimulation of Azotobacter.

Discussion of data for unlimed plots.—Extensive studies on the presence of Azotobacter in soils of different reactions were made by Gainey (3) who found a critical reaction of pH 6.0 for the growth of this organism. In the spring of 1928 the unlimed ends of the plots of sections C and D were sampled and the samples analyzed for Azotobacter. Azotobacter was found to be absent in all but 1 of the 60 unlimed soils tested (tables 2 and 3). This soil was from plot 30 of section C and had a count of one colony per gram. This plot lies adjacent to the limestone road previously mentioned and has received enough lime from this source to raise the reaction to pH 6.0. The foregoing data have been obtained by a quantitative study on Azotobacter and tend to confirm the qualitative results obtained by Gainey.

It is believed that this paper presents the first quantitative data published concerning the effects of lime and fertilizer treatments on the growth and activity of Azotobacter colonies in soil.

SUMMARY

The agar plate method, an adaptation of the Winogradsky silica gel plate method for determining the number of Azotobacter colonies in soil has been developed, and factors influencing its use have been studied. A study of the

Azotobacter flora on the 5-year rotation plots at Wooster has been carried on during 1927, 1928, and 1929. The following statements appear to be justified by the data obtained:

In general the Azotobacter population has been much greater in the limed check plots than in the limed plots which receive fertilizer treatments.

Additions of nitrate of soda have been followed by greater growth of Azotobacter than additions of either superphosphate or muriate of potash.

Additions of manure have resulted in a depression of the Azotobacter flora.

It has not been possible to correlate Azotobacter populations and crop yields in the check plots.

Azotobacter colonies have not been found in soils which have a reaction more acid than pH 6.0.

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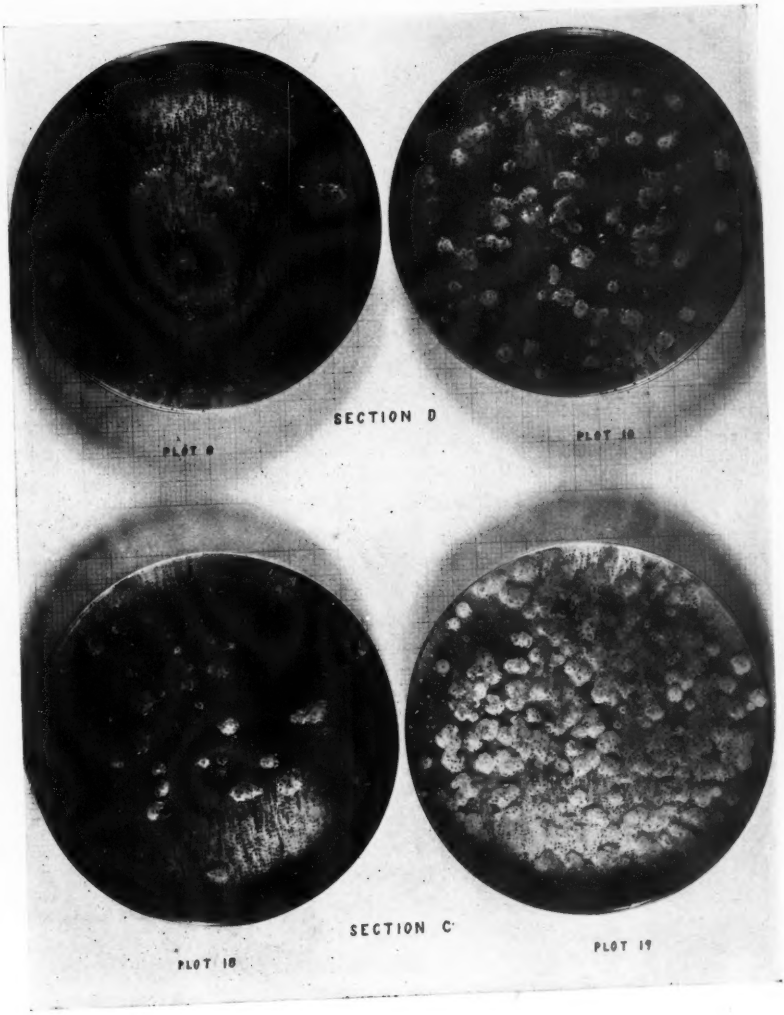
PLATE 1

RANGE OF COLONY COUNTS


SECTION D
PLOT 9
PLOT 10
SECTION C
PLOT 18
PLOT 19

THE CARBON-ORGANIC MATTER FACTOR IN FOREST SOIL HUMUS

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It is generally recognized that the most reliable measure of the organic matter content of the soil is the amount of organic carbon present. Comparisons are then made either as carbon or else on the basis of organic matter obtained by the use of the factor 1.724.

As is well known, this factor was obtained by Schulze, Wolff, Van Bemmelen, and others (3, 4, 5, 8) in the latter part of the nineteenth century and has been used rather freely since then. It is based on the assumption that the carbon content of soil organic matter is 58 per cent. Some doubts have been raised from time to time as to the advisability of applying the factor too generally. Read and Ridgell (5) from a study of 37 soils came to the conclusion that if a factor is to be used it should be based on 51 or 52 per cent carbon rather than 58 per cent. They preferred using nitrogen instead of carbon as a basis for calculating the organic matter content. Leighty and Shorey (4), and more recently Waksman (8), maintain that the equation, $N \times 20 = O.\ M.$, is untrustworthy for general use. Waksman states that the method, $C \times 1.724 = O.\ M.$, proposed by those earlier soil chemists is ". . . . still the most reliable that we have at the present time for measuring the total organic matter of the soil."

The foregoing discussion is meant to refer primarily to the mineral layers of the average soil. The question arises, is the factor 1.724 equally applicable to peat soils and to the organic horizons of forest soils?

Since, in the case of mineral soils, loss on ignition is not a reliable measure of the organic matter content, and since an exact method for this determination has not yet been found, it has been necessary, as Waksman states, to use a factor in connection with the organic carbon content. On the other hand, the loss-on-ignition data for organic materials such as peats and forest litter are a very close if not an exact measure of the total organic matter, and one need not depend upon the carbon analysis with a correcting factor. Nevertheless, such a factor is a convenience especially in making comparisons with other soil horizons.

As was mentioned previously, the factor 1.724 assumes a carbon content of 58 per cent. There is considerable evidence, however, to show that the carbon content of highly organic material such as peats and forest litter is less than 58 per cent and therefore the factor 1.724 is too low.

In 1916, Gortner (3) reported a factor of 1.842 for peats, and 1.971 for vege-

table materials such as alfalfa, oats, oak leaves, fern leaves, and grass. As he obtained these results from only a few samples he entertained the hope that some one would make further studies on the problem. Robinson, McLean, and Williams (6) found an average carbon percentage of 52.95 for four peats, giving a factor of 1.888. Alway and Harmer (1) working with forest floor material from forests in three different localities in Minnesota obtained the factors 1.86, 1.89, and 1.85. Two of the localities were in the deciduous forest belt, whereas the third was farther north in the coniferous region. These investigators included all of the dead material overlying the mineral soil, separation into litter and "F" and "H" layers not being made. They state:

> The weight per acre of organic matter, computed from the organic carbon, is about one-eleventh less than the weight of volatile matter. This difference is probably due to the presence of so-called *water of constitution* which is driven off while the organic matter is undergoing oxidation, and may be due in part to the factor used—1.724—being too low.

EXPERIMENTAL

Forest soil investigations at the Connecticut Agricultural Experiment Station include the determination of the organic carbon and the ash of the organic horizons. Carbon analyses were made by either the wet combustion method (2) using the Meyer bulb tube instead of the usual absorption tower, or the dry combustion method (2) using the Parr apparatus. Either method gave satisfactory results, but the former has been abandoned in favor of the latter as more suitable to this laboratory. Ashing was carried out according to the official methods.

It is our practice in detailed forest soil studies to recognize as many as three types of leaf material constituting the A_0 horizon: the freshly fallen leaves or *litter;* the partially decomposed and still decomposing "F" or *fermentation* layer often called "duff;" and the well-decomposed, structureless "H" or *humification*[1] layer.

When the data from the organic carbon analyses were plotted against that of the ash content excellent correlation was observed, as would be expected. It was seen at once, however, that the percentage of carbon in the organic matter falls somewhat short of 58 and the resulting factor $\left(\text{factor} = \frac{100}{\text{per cent C}}\right)$ would be greater than 1.724.

Furthermore, some scattering of the points was evident and when investigated it was found that a more or less distinct separation of the samples could be made, based on the three types of material mentioned in the foregoing. Dividing the loss-on-ignition (100—ash content) of each sample by its respective carbon content, we have an average factor of 1.892 ± 0.0057 for 14 samples of litter; 1.854 ± 0.0038 for the duff (55 samples); and 1.799 ± 0.0074 for the

[1] The terms *fermentation* and *humification* were proposed at the 1930 meeting of the Association of Soil Survey Workers, to be applied to the horizons in forest soils which Hesselman has called the "F" layer, from the Swedish "Formultningsskiktet" and the "H" layer from the Swedish "Humusamneskiktet," respectively.

TABLE 1

Loss on ignition, carbon, and resulting factors of the several organic horizons of forest soils

$$\left(\text{Factor} = \frac{\text{Loss on ignition}}{\text{Per cent C}} \times 100\right)$$

SOIL NUMBER	LOSS ON IGNITION	C	FACTOR
	Per cent	Per cent	
	Litter material		
F 192	96.48	52.78	1.827
F 313	95.88	50.19	1.910
F 426	95.84	51.15	1.874
F 379	95.81	52.41	1.828
F 419	95.52	49.35	1.935
F 317	95.22	50.76	1.876
F 305	94.62	50.10	1.889
F 377	94.49	49.43	1.911
F 315	94.22	49.59	1.900
F 180	93.71	49.01	1.912
F 400	92.00	48.20	1.909
F 178	91.47	47.83	1.912
F 309	89.87	47.07	1.909
F 176	79.08	41.57	1.902
Average			1.892 ±0.0057
	"F" or fermentation layers		
G 14	98.15	53.50	1.834
F 346	96.92	51.50	1.882
G 20	96.82	52.70	1.837
F 333	95.91	50.45	1.901
F 363	95.69	51.80	1.847
G 38	95.62	52.50	1.821
F 306	95.48	52.00	1.836
F 380	94.82	52.57	1.804
F 185	94.57	50.47	1.874
G 21	94.35	51.00	1.850
F 367	94.31	51.21	1.842
G 36	94.25	49.75	1.894
G 16	93.90	50.60	1.856
G 18	93.64	50.20	1.865
F 246	93.38	49.10	1.902
F 311	93.36	49.33	1.892
F 271	93.35	48.30	1.933
F 299	93.34	48.80	1.913
G 35	93.31	49.40	1.889
F 192.1	93.23	51.23	1.820
G 23	92.27	49.50	1.864
G 39	92.01	50.00	1.840
F 373	91.86	50.58	1.816

TABLE 1—*Continued*

SOIL NUMBER	LOSS ON IGNITION	C	FACTOR
	Per cent	Per cent	
"F" or fermentation layers—Concluded			
G 30	91.54	49.40	1.853
G 17	91.50	48.80	1.875
G 32	91.49	49.45	1.850
G 33	90.95	49.50	1.837
F 200	90.85	48.73	1.864
G 37	90.83	48.30	1.880
F 32	90.55	49.20	1.840
F 51	90.00	48.80	1.844
F 427	89.79	48.20	1.863
S 358	88.50	47.50	1.863
F 420	88.28	46.20	1.911
F 119	88.28	46.70	1.890
F 239	87.60	46.55	1.882
F 44	87.52	48.70	1.797
F 9	87.09	49.10	1.774
F 207	87.00	45.80	1.899
F 407	86.80	46.55	1.865
F 285	86.72	45.50	1.906
F 76	86.17	45.45	1.896
F 112	84.72	44.90	1.887
S 362	84.50	45.50	1.857
F 103	84.00	44.75	1.877
F 91	83.93	47.01	1.785
F 265	81.00	42.80	1.892
F 97	78.65	41.55	1.893
F 106	77.35	42.15	1.835
F 25	76.10	42.30	1.799
F 17	70.30	41.05	1.712
F 109	68.75	37.90	1.814
F 69	67.50	37.50	1.800
F 413	66.56	36.22	1.838
F 38	55.60	31.08	1.789
Average			1.854 ±0.0038
"H" or humification layers			
F 193	96.21	53.97	1.783
F 186	92.85	49.00	1.894
F 5	91.55	52.75	1.736
F 6	91.36	52.80	1.730
F 18	86.80	49.50	1.754
F 381	85.53	49.35	1.734
F 318	83.98	47.22	1.778
F 10	83.90	48.20	1.741
F 45	82.63	46.37	1.782

TABLE 1—*Concluded*

SOIL NUMBER	LOSS ON IGNITION	C	FACTOR
	Per cent	Per cent	
"H" or humification layers—Concluded			
F 307	81.40	46.68	1.744
F 33	80.90	43.40	1.864
F 311½	79.12	43.04	1.838
F 187	79.06	45.02	1.756
F 26	80.49	44.83	1.795
F 368	71.30	39.75	1.794
F 52	71.20	38.58	1.845
F 364	70.83	38.13	1.857
F 194	67.93	38.04	1.786
S 359	65.90	35.80	1.841
F 370	63.60	36.62	1.737
F 113	60.90	32.50	1.874
F 120	49.00	27.41	1.788
F 428	35.60	19.56	1.820
F 70	34.40	18.10	1.900
Average			1.799 ±0.0074

humus material (24 samples). The loss on ignition, carbon content, and the resulting factors are found in table 1.

Calculated as per cent carbon $\left(C = \frac{1}{\text{factor}}\right)$ the results are, for the litter 52.85; for the duff, 53.94; and for the humus material, 55.58 per cent.

The proportional increase in the carbon content with progressive decomposition is due to the disappearance of the pentosans and celluloses, which have a relatively low carbon content of 42–44 per cent, and the accumulation of lignins and synthesized cell material with a high carbon content, 62–64 per cent (7, p. 675; 8).

When the data for organic matter obtained by the old factor (C × 1.724) and those obtained by the proposed factors (C × 1.892, 1.854, and 1.799 for the litter, duff, and humus respectively) are compared with the figures for the loss on ignition, and the whole is subjected to statistical analysis, we have the following results:

	C × 1.724	*C × New factors*	*Loss on ignition*
Per cent organic matter (average of 93 samples)	79.6	85.4	85.3

Coefficient of correlation[2] *(Pearson's method)*

Between C × 1.724 and loss on ignition	*Between C × 1.892, 1.854, or 1.799 and loss on ignition*
0.975 ±0.0035	0.983 ±0.0024

[2] Jones, D. F. 1925 Genetics in Plant and Animal Improvement, p. 198–201. John Wiley and Sons, Inc., New York.

The degree of correlation is seen to be considerably higher in the second case than in the first; also the probable error is less in the second case. This establishes beyond a doubt the greater reliability of the new factors.

These results substantiate those of Gortner (3), Robinson, McLean, and Williams (6) and Alway and Harmer (1), all of which indicate a lower carbon content than 58 per cent and a factor above 1.724 for materials high in organic matter.

In an endeavor to ascertain whether or not the factors might differ for different forest types, a separation was made into the following classes: young hardwoods (40 years or less), mature hardwoods, mixed hardwoods and conifers (the latter usually hemlock), red pine, white pine, and spruce-hardwoods type from the White Mountains section of New Hampshire.

The results of the comparisons on this basis were practically negative, there being no consistent difference, with the exception of the spruce-hardwoods type from New Hampshire, which gave a somewhat lower factor for the "F" and "H" materials. This was not wholly unexpected considering the difference in latitude and elevation between Connecticut and the locality sampled in New Hampshire. Furthermore, the material came from forests which for the most part are older and have been subject to less disturbance in the past than have those of Connecticut. The organic horizons present consequently are thicker; they have been subjected to decomposition for a longer period of time; and probably contain a larger proportion of the more resistant lignins, cutins, tannins, etc.

CONCLUSIONS

The results of this study together with those of other investigators indicate quite definitely that the carbon content of carbohydrate-rich materials such as forest litter and peat is less than 58 per cent and therefore the conversion factor 1.724 is too low. Although no work relative to this problem has been done at this station on peats, from the results obtained by Gortner (3) and Robinson, McLean, and Williams (6) it would appear that a factor of about 1.86 is approximately correct.

In the case of the organic layers of forest soil, the stage of decomposition cannot be ignored. For the freshly fallen leaves which have not undergone decomposition to any extent 1.89 is very nearly correct; for the decomposing fermentation or duff layers 1.85; and for the well-decomposed, structureless humus, 1.80.

These factors are equally applicable to all the common forest types such as hardwoods, conifers, and hardwood-conifer mixtures found in New England. When the work of investigators in other parts of the country is considered it would appear that the factors recommended in the foregoing may be of more or less universal application.

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THE EFFECT OF VARIOUS SOURCES OF ORGANIC MATTER ON THE PROPERTIES OF SOILS AS DETERMINED BY PHYSICAL MEASUREMENTS AND PLANT GROWTH[1]

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The advent of the internal combustion engine and its substitution for animal power on farms and in cities has greatly reduced the quantity of manure available for use in growing plants. This reduction is particularly marked in regions adjacent to centers of population, where large quantities of manure are utilized for truck gardening, lawns, flower beds, home gardens, parks, and golf courses. The increasing uncertainty as to the quantity and quality of manure still obtainable has stimulated search for satisfactory substitutes.

Users of these substitutes have come to realize that peats, mucks, spent mushroom soil, etc., are not identical with manure in their effect on soils. Part of this difference is undoubtedly due to the relative quantities of avilable nutrients carried by the various materials, but a further part is the result of differences in physical characteristics. Inasmuch as nutrients may be supplied to plants quite as efficiently in commercial fertilizers as in manure, it is important that information be obtained as to the relative effectiveness of various types of organic matter in producing a desirable physical condition of the soil.

Various workers (1, 4, 5, 7) in America and in Europe have called attention to the relation between organic matter in soils and such physical properties as the hygroscopic coefficient, maximum water holding capacity, available water, porosity, and tilth. Certain writers have expressed the opinion that the physical condition of a soil may influence its productivity quite as much as the chemical composition. Changes in moisture and air relationships in the soil not only modify plant growth directly, but they also greatly modify the chemical and biological conditions in the soil and thus affect the plant indirectly.

EXPERIMENTAL METHODS

A greenhouse experiment was conducted during the winter of 1929–30 to determine the relative value of several types of organic matter in modifying

[1] The research here reported was made possible by the financial support of the Hyper-Humus Company of Newton, N. J.

[2] Journal Series paper of the New Jersey Agricultural Experiment Station, department of agronomy.

soils for the growth of bent grass. Five types or sources of organic matter were used: well-rotted stable manure; spent mushroom soil from mushroom houses in Pennsylvania; raw peat from Capac, Michigan; cultivated peat from Newton, New Jersey, and granulated peat moss from Europe. Each of these materials is available in considerable quantities and the quality is fairly uniform. Three soils were selected: a loam and a clay loam of the Sassafras series, and a sandy soil made by mixing 3 parts of sand with 1 part of loam soil.

pH values of the organic materials and soils were obtained by means of a potentiometer with a quinhydrone electrode; and loss on ignition was employed to determine the quantity of organic matter present. Calcium and magnesium were determined from ignited material, the calcium being obtained as calcium oxalate, which was dissolved with sulfuric acid and the resulting oxalic acid titrated with standard potassium permanganate. Magnesium was weighed as magnesium pyrophosphate.

A number of physical constants were used to measure differences in the characteristics of the various organic materials separately, and in mixtures with soil. Hygroscopic coefficients were obtained by exposing air-dry soils in a saturated atmosphere, followed by drying. The available water holding capacity was determined by subtracting the wilting coefficient [indirectly obtained from the hygroscopic coefficient (2)] from the maximum water holding capacity. To determine this latter constant, a part of the soil or material was first saturated, and then sampled after allowing the gravitational water to drain off. Maximum water holding capacities determined in this manner are lower than those found with the Hilgard cup, but the data are regarded as more nearly approaching field water capacities. The rate of percolation of water through each soil was determined by adding water to a hollow cylinder 4 inches in diameter, placed upright with one end inserted into the soil. Sufficient water was added to maintain a depth of at least one-fourth inch above the soil surface, and the quantity collected from the drain in the bottom of the pot in a given period of time furnished the index desired. Pore space was calculated from samples taken with the special tube described by Lebedeff (6).

Mixtures were made of each of the three soils with the five sources of organic matter, at a light and a heavy rate. For the light rate, 73.5 gm. (dry basis) of each type of organic matter were thoroughly mixed with 3,900 gm. of moisture-free soil; and for the heavy rate, 147 gm. of organic matter were added to 3,900 gm. of soil. These quantities are approximately equivalent to 40 and 80 tons, respectively, of material containing 50 per cent moisture applied to an acre of land $6\frac{2}{3}$ inches deep. Each mixture was made in duplicate, thus requiring 20 pots for each soil class, in addition to 2 pots of the untreated soil. Nine-inch porous clay flower pots were used, which were coated on the inside with black asphalt paint to prevent undue evaporation through the walls. Determinations of hygroscopic coefficients, maximum water holding capacity, and loss on ignition were made for each soil mixture at the beginning of the experiment.

After the soil had been firmly packed in, South German mixed bent grass seed was planted on November 18, at the rate of 1 gm. of seed to each pot. The soils were thoroughly moistened at the time of seeding, and thereafter received about 370 cc. of water weekly, the equivalent of 2 inches of rain monthly. For the most part, water was added twice each week, but whenever transpiration was excessive and the grass appeared to be suffering from drouth, an additional supply was provided uniformly for the entire series. Sporadic outbreaks of "brown patch" caused by *Rhizoctonia* spp. were controlled by sprinkling with a dilute solution of mercuric chloride.

Records were kept of atmospheric conditions in the greenhouse during the period covered by the experiment. The mean temperature for the entire 19 weeks was 66°F. This is 6° lower than mean temperatures in the field for a period of equal length from May to September in 1929. The extremes, however, were much greater in the field than in the greenhouse, and the greenhouse temperatures may be regarded as being favorable for grass growth. Total water loss in the greenhouse as measured by an atmometer averaged 105 cc. a week, whereas in the field during the summer of 1929 it averaged 171 cc. The reduced evaporating power of the air in the greenhouse and the uniform supply of moisture largely prevented any serious injury through lack of water, even though the quantity added was comparatively light.

Since the experiment was designed to reveal only the physical effects on the soil of the several types of organic matter, sulfate of ammonia was added in liberal quantities to meet the nutrient requirements of the crop. One-half gram of this fertilizer was supplied in solution to each pot once a month. In turf culture, this quantity has been found ample for maintaining vigorous growth of grass.

At the end of 19 weeks the grass tops were harvested and dry weights obtained. The rate of percolation of water through each soil was then determined. The soils were again sampled to determine their maximum water holding capacities, followed by further sampling to obtain data on pore space. After sieving to remove grass roots, each soil was tested to determine the hygroscopic coefficient and the loss on ignition.

CHARACTERISTICS OF THE MATERIALS USED

The soils included in the experiment were mildly acid in reaction, and the organic content as measured by loss on ignition was medium for the loam and clay loam (table 1). The available water holding capacity was 17.4 per cent for the sandy soil, 32.7 per cent for the loam, and 25.7 per cent for the clay loam. The comparatively low value of the clay loam may be attributed to its poor tilth.

The types of organic matter varied greatly in their physical properties. The manure which had been allowed to decay for one year, was dark brown and easily broken into fragments when partially dried. The spent mushroom soil obtained from mushroom beds near Philadelphia, was originally made by

alternating layers of strawy manures and loam or clay loam. Upon removal from the beds, the rotted manure was thoroughly mixed with the layers of soil, in which form it was used in these experiments. The organic matter of this mixture had been more completely transformed in appearance than the well-rotted manure described in the foregoing. The imported peat moss was light brown and very fibrous, but no large lumps were present. The raw peat from Michigan was dark brown and coarsely fibrous. The cultivated peat from New Jersey had lost its fiber, become finely granular, and dark brown to black as a result of the tillage.

The peats and peat moss were strongly acid in reaction, whereas the spent mushroom soil was nearly neutral and the manure distinctly alkaline. Loss

TABLE 1

Characteristics of the materials used in the tests

MATERIALS AND SOURCES	ACIDITY VALUES	TOTAL OXIDES OF CALCIUM AND MAGNESIUM	LOSS ON IGNITION	HYGROSCOPIC COEFFICIENT	MAXIMUM WATER HOLDING CAPACITY	AVAILABLE WATER HOLDING CAPACITY*
	pH	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Types of organic matter:						
Cultivated peat, Newton, New Jersey	5.05	3.47	87.8	51.0	267.6	192.6
Raw peat, Capac, Michigan	4.03	0.80	90.1	39.9	346.4	287.7
Imported peat moss, Europe	4.42	0.34	97.1	54.6	1,034.9	954.6
Spent mushroom soil, Pennsylvania	6.65	1.56	23.9	25.1	70.5	33.6
Well-rotted stable manure, New Jersey	8.50	2.38	68.9	76.7	288.3	175.4
Soil classes:						
Sandy soil	5.80	....	2.6	2.2	20.6	17.4
Loam	6.10	....	6.8	3.9	38.4	32.7
Clay loam	5.93	....	6.5	7.2	36.2	25.7

* Available water holding capacity determined by subtracting the wilting coefficient (indirectly determined from hygroscopic coefficient) from the maximum water holding capacity.

on ignition data indicate a far higher organic matter content for the three peats than for manure, whereas the mushroom soil contained only about one-third as much. The hygroscopic coefficients of the organic materials were not proportional to their organic content. Thus, the coefficient of New Jersey peat was 11.1 per cent greater than that of Michigan peat, although the organic content of the latter was slightly higher.

The maximum water holding capacities of the peats compared very favorably with manure, but spent mushroom soil showed a comparatively low capacity. The imported peat moss possessed the greatest capacity for total water, and also for water available to plants. This material, however, absorbed water very slowly. In order to insure complete saturation of the particles, it was

necessary to plug the bottom of the flower pot containing the peat moss, add an excess of water and allow it to stand for 24 hours. This property was not apparent in New Jersey peat, unless it had been first thoroughly air-dried. In agricultural practice, the slow water absorption of dry peat may cause trouble when the material is mixed with soil in droughty periods. Layers of peat placed below the surface of the soil may also be harmful for the same reason if they are thoroughly dry when laid down, or become dry later on.

EXPERIMENTAL RESULTS ON SANDY SOIL

Sandy soils are notoriously low in water holding capacity, and are frequently so open that water passes through rapidly without greatly benefiting plant growth. The admixture of organic matter or clay to such soils is usually recommended to correct their deficiencies. In these investigations, the addition of the peaty materials, spent mushroom soil, or manure increased the capacity to retain available water, when this property was measured after grass had been grown on the soil mixtures for 19 weeks (table 2). The imported peat proved most effective in this respect, but considerable difficulty was experienced at the beginning of the experiment in keeping the soil mixture containing this material sufficiently moist to germinate seed.

The data indicate that some time is required before the full effectiveness of organic materials in raising the water holding capacity is attained; and for certain materials, such as manure and peat moss, this increase in effectiveness is more than offset by their rapid loss through decomposition. From the practical standpoint, it is noteworthy that the peats have been more valuable for increasing moisture capacity than has well-rotted manure. Although spent mushroom soil improved the water relations of the soil, it was not so effective as manure for the period covered by the experiment. It is also apparent from the data that doubling the quantity of organic matter raised the water holding capacity of the soil in every case.

Cultivated New Jersey peat, raw Michigan peat, and spent mushroom soil reduced the pore space of sandy soils; however, large quantities were less efficient than smaller additions. Manure proved less effective in reducing pore space than did the aforementioned materials, and peat moss was in turn less effective than manure since it actually increased total pore space when used at the heavier rate.

Percolation rates were roughly correlated with pore space of the soil mixtures. Cultivated New Jersey peat reduced percolation to a lower value than any other material. Spent mushroom soil and raw Michigan peat also reduced percolation considerably below that of the untreated soil. Light applications of peat moss or manure likewise lowered the rate of percolation, but the heavier applications greatly increased it.

Grass yields produced on these soil mixtures may be taken as a measure of the effectiveness with which these organic materials modified the soil for plant growth. In general, these yields indicate that heavy applications were more

valuable than light additions, with all types of organic matter greatly improving the productivity of the sandy soil. Yields were not highly correlated with the increases in available water holding capacities of the various mixtures. Thus, although mixtures containing cultivated New Jersey peat did not average so high in water holding capacity as those containing Michigan peat, the yields

TABLE 2

The effect of different types of organic matter additions on the physical properties of a sandy soil, and on the yields of grass produced

TYPE OF MATERIAL MIXED WITH THE SOIL	AVAILABLE WATER HOLDING CAPACITY*		PORE SPACE OF SOIL AFTER GROWTH OF GRASS		PERCOLATION OF WATER IN 15 MINUTES	GRASS YIELDS PER POT (DRY WEIGHT OF TOPS)
	Before growth of grass	After growth of grass	Actual	Difference from check		
	per cent	*per cent*	*per cent*	*per cent*	*cc.*	*gm.*
A. Light additions of organic matter—73.5 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	14.9	18.1	47.1	−18.2	286	9.3
Raw Michigan Peat	17.6	20.0	50.5	−12.3	469	8.7
Imported peat moss	24.2	24.7	56.9	−1.2	678	9.4
Spent mushroom soil	15.5	16.2	49.2	−14.6	417	9.4
Well-rotted manure	20.2	17.1	50.1	−13.0	639	11.5
B. Heavy additions of organic matter—147.0 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	20.1	21.2	50.0	−13.2	298	10.3
Raw Michigan peat	24.6	20.4	53.7	−6.8	535	9.1
Imported peat moss	33.8	30.5	62.9	+9.2	1,102	10.6
Spent mushroom soil	18.5	19.4	52.4	−9.0	436	9.6
Well-rotted manure	23.8	19.5	55.3	−4.0	1,052	9.3
Average of both light and heavy additions of organic matter						
Cultivated New Jersey peat	17.5	19.6	48.5	−15.8	292	9.8
Raw Michigan peat	21.1	20.2	52.1	−9.5	502	8.9
Imported peat moss	29.0	27.6	59.9	+4.0	890	10.0
Spent mushroom soil	17.0	17.8	50.8	−11.8	426	9.5
Well-rotted manure	22.0	18.3	52.7	−8.5	845	10.4
Check—no organic matter added	17.4	16.1	57.6	...	767	6.2

* Available water holding capacity determined by subtracting the wilting coefficient (indirectly determined from hygroscopic coefficient) from the maximum water holding capacity.

of grass on the former were much higher. Also, New Jersey peat mixtures produced nearly as heavy yields of grass as those containing peat moss, although the moisture retaining power of the peat moss mixtures was far greater.

The explanation for the different effects of the various types of organic matter seems to lie in the modification of the soil structure. Moisture was supplied to the grass in this experiment in periodic waterings once or twice

each week. Soil mixtures which were extremely porous permitted more rapid percolation than soils which were less open. Surface evaporation from open soils must also have been relatively great. Therefore, the increased potential ability of the mixtures to retain moisture was not fully utilized when the relatively coarse textured peat moss and raw Michigan peat were incorporated. It seems probable that such conditions may also exist in the field when moisture is supplied in relatively large amounts over a short period of time, as in thundershowers, or periodic heavy waterings. These results indicate that fine textured materials such as cultivated peat and spent mushroom soil are more suitable substitutes for manure on sandy soils than coarse textured materials such as raw Michigan peat and imported peat moss.

EXPERIMENTAL RESULTS WITH A LOAM SOIL

The data obtained from mixtures of loam soil with each of the organic matter sources, when compared with those from sandy soil, show that the manure substitutes do not effect all soil types similarly (table 3). The loam used in these tests had a fairly high organic matter content before treatment, and with the system of limited watering followed, one should not expect so marked an effect from additions of organic matter as for sandy soil. However, the incorporation of every type of organic matter increased the available water holding capacity of the loam. Imported peat moss was most effective in raising the moisture retaining power, with raw Michigan peat, manure, cultivated New Jersey peat, and spent mushroom soil following in the order named. With the exception of the spent mushroom soil, the ability of the mixtures to retain moisture was greater after the growth of grass than when the organic matter was first incorporated.

Pore space of the loam soil was not greatly changed by the addition of any type of organic matter, except peat moss. This latter type of material markedly increased the pore space, particularly when used at the heavier rate. Peat moss was also the only material which notably increased the percolation rate of water. When used at the lighter rate, all of the materials reduced percolation. Soil mixtures receiving heavy additions of each material had higher rates of percolation, and in the case of peat moss and Michigan peat, these rates exceeded that for untreated loam.

It is evident from the yields of grass obtained that the open structure produced by heavy additions of peat moss was less desirable for plant growth than a more compact structure. For all other treatments the grass yields were 13 to 40 per cent greater than on untreated soil. There was a fairly close correlation between available water holding capacity of the treated soils and the yields of grass produced, if the heavy application of peat moss is disregarded. Apparently, the addition of organic matter to the soil permitted more complete utilization of the comparatively scanty moisture supply, except where the structure had become exceedingly open as the result of the treatment given.

Cultivated New Jersey peat and raw peat from Michigan were about equally valuable for improving the loam soil for plant growth, and both were moderately satisfactory as substitutes for manure. Peat moss seems to be valuable for modifying the physical condition of this soil, only when used in moderate quantities. Under conditions of abundant moisture, peat moss may possibly be

TABLE 3

The effect of different types of organic matter additions on the physical properties of a loam soil, and on the yields of grass produced

TYPE OF MATERIAL MIXED WITH THE SOIL	AVAILABLE WATER HOLDING CAPACITY*		PORE SPACE OF SOIL AFTER GROWTH OF GRASS		PERCOLATION OF WATER IN 30 MINUTES	GRASS YIELDS PER POT (DRY WEIGHT OF TOPS)
	Before growth of grass	After growth of grass	Actual	Difference from check		
	per cent	*per cent*	*per cent*	*per cent*	*cc.*	*gm.*
A. Light additions of organic matter—73.5 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	33.2	35.8	59.5	−5.0	354	12.9
Raw Michigan peat	35.6	35.6	61.1	−2.4	458	12.0
Imported peat moss	37.2	38.9	65.5	+4.6	592	13.5
Spent mushroom soil	33.1	33.4	62.7	+0.2	491	13.3
Well-rotted manure	33.9	35.1	62.9	+0.5	472	13.0
B. Heavy additions of organic matter—147.0 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	32.6	33.5	63.9	+2.1	595	12.7
Raw Michigan peat	37.5	39.0	66.3	+5.9	800	13.4
Imported peat moss	42.1	46.5	69.9	+11.7	1,235	9.9
Spent mushroom soil	32.7	31.2	61.0	−2.6	485	12.2
Well-rotted manure	34.0	35.1	63.8	+1.9	595	14.8
Average of both light and heavy additions of organic matter						
Cultivated New Jersey peat	32.9	34.6	61.7	−1.4	474	12.8
Raw Michigan peat	36.5	37.3	63.7	+1.8	629	12.7
Imported peat moss	39.6	42.7	67.7	+8.1	913	11.7
Spent mushroom soil	32.9	32.3	61.8	−1.4	488	12.7
Well-rotted manure	33.9	35.1	63.3	+1.1	533	13.9
Check—no organic matter added	32.8	31.0	62.6	...	682	10.6

* Available water holding capacity determining by subtracting the wilting coefficient (indirectly determined from the hygroscopic coefficient) from the maximum water holding capacity.

useful in heavier amounts. Apparently less physical improvement is produced by the incorporation of spent mushroom soil in liberal quantities than from the use of manure, cultivated peat, or raw Michigan peat. This behavior may be attributed to its comparatively low content of organic matter and high content of silt and clay.

EXPERIMENTAL RESULTS WITH A CLAY LOAM SOIL

The addition of organic matter of any type improved the water holding capacity of the clay loam soil; and further, heavy additions were more effective than light ones in this respect (table 4). Spent mushroom soil was least effective in bringing about this change whereas imported peat moss proved most

TABLE 4

The effect of different types of organic matter additions on the physical properties of a clay loam soil, and on yields of grass produced

TYPE OF MATERIAL ADDED TO THE SOIL	AVAILABLE WATER HOLDING CAPACITY*		PORE SPACE OF SOILS AFTER GROWTH OF GRASS		PERCOLATION OF WATER IN 30 MINUTES	GRASS YIELDS PER POT (DRY WEIGHT OF TOPS)
	Before growth of grass	After growth of grass	Actual	Difference from check		
	per cent	*per cent*	*per cent*	*per cent*	*cc.*	*gm.*
A. Light additions of organic matter—73.5 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	29.0	28.0	60.0	+0.7	333	11.3
Raw Michigan peat	31.5	30.3	62.8	+5.4	227	11.3
Imported peat moss	36.8	33.3	64.6	+8.4	896	11.4
Spent mushroom soil	30.7	27.3	60.1	+0.8	287	11.3
Well-rotted manure	32.1	29.8	61.4	+3.0	232	11.5
B. Heavy additions of organic matter—147.0 gm. dry matter to 3,900 gm. moisture-free soil						
Cultivated New Jersey peat	31.0	30.1	62.7	+5.2	515	10.8
Raw Michigan peat	35.9	33.4	64.9	+8.9	805	10.9
Imported peat moss	39.9	35.0	69.0	+15.8	1,562	10.3
Spent mushroom soil	30.8	28.0	62.2	+4.4	290	12.0
Well-rotted manure	31.1	32.9	64.1	+7.6	885	11.7
Average of both light and heavy additions of organic matter						
Cultivated New Jersey peat	30.0	29.0	61.3	+2.9	424	11.0
Raw Michigan peat	33.7	31.8	63.8	+7.0	516	11.1
Imported peat moss	38.3	34.1	66.8	−12.0	1,229	10.8
Spent mushroom soil	30.7	27.6	61.1	+2.5	288	11.6
Well-rotted manure	31.6	31.3	62.7	+5.2	558	11.6
Check—no organic matter added	26.7	26.0	59.6	...	320	9.6

* Available water holding capacity determined by subtracting the wilting coefficient (indirectly determined from the hygroscopic coefficient) from the maximum water holding capacity.

effective. Cultivated New Jersey peat was slightly less efficient, and raw Michigan peat somewhat more efficient than manure in raising the moisture retaining power of the clay loam.

Spent mushroom soil likewise produced the least change in pore space, although each of the materials increased this property. Peat moss additions

caused the greatest modification, raising the percentage from 59.6 for untreated soil to 69.0 when heavy additions were made. Cultivated peat was less effective than manure whereas raw Michigan peat was more effective in raising the percentage of pore space.

Percolation rate for the untreated clay loam was not so low as might be expected, largely because numerous cracks developed under the system of light watering, and water added to the surface passed downward through these channels without actually moving through the body of the soil itself. The addition of organic matter in any form, except spent mushroom soil, prevented the formation of cracks in the soil mass and also produced an appreciable increase in the rate of percolation. In the case of manure and the three types of peat, heavy applications brought percolation rates to a higher point than light additions. It is noteworthy that the effectiveness of the five types of materials compared varied, with their texture. Spent mushroom soil being largely composed of silt and clay produced the least change, and the granular cultivated peat had considerably less influence than the fibrous peat from Michigan. The large increase in percolation rate which resulted from the use of peat moss is associated with its fibrous condition and bulky nature.

From a practical standpoint it is apparent that the incorporation of very large quantities of peat moss under conditions of limited moisture supply may produce an undesirable medium for plant growth, because of the increase in porosity and percolation, and the very slow absorption of water by the peat moss when it has become air-dry. On the other hand, it is evident that organic materials of a fibrous nature are more effective in improving the physical condition of a heavy clay loam than those which are largely non-fibrous. It seems likely that this difference would be even more noticeable under conditions of excessive moisture supply which tend to make the soil more compact.

The yields of grass produced on the clay loam mixtures were in every case considerably higher than for untreated clay loam. The productivity of the mixtures was not closely associated with the changes produced in their physical properties. Thus, imported peat moss produced the lowest yields, even though it was most effective in changing the physical nature of the soil. Spent mushroom soil modified the soil least, but produced as large yields of grass as manure. Cultivated New Jersey peat proved about as efficient as raw Michigan peat in stimulating plant growth, both being nearly as effective as manure.

The relative value of each manure substitute on heavy soils cannot be determined from these data alone. A similar experiment conducted under conditions of abundant moisture supply should supplement these findings and permit the formulation of more definite conclusions. These data taken alone seem to indicate that additions of organic matter to clay loams of this type are beneficial to plant growth and that materials which are moderately fibrous are satisfactory substitutes for manure. However, the addition of organic matter of any type seems desirable; the question being one of the relative effectiveness of the various types.

THE PERSISTENCE OF ORGANIC MATTER

One of the important considerations in choosing a source of organic matter for the modification of any soil, is the length of time the material will persist and exert its influence. To obtain this information for each type of organic matter under test, data were obtained for loss on ignition of the soil mixtures at the beginning of the experiment and again after grass had been grown on the soils for 19 weeks. These data (table 5) show that the persistence varies with soil type, losses being about three times as great in the sandy soil as in the clay loam. For any one soil, however, considerable difference in rapidity of decomposition was observed between the various types of organic matter.

When data from all three soils were averaged, 17.4 per cent of the native organic matter present was found to have been lost during the period of 19 weeks when grass was grown on the untreated soil. Soil mixtures containing mush-

TABLE 5

Persistence of organic matter mixed with soil and cropped to grass, as measured by loss on ignition before and after cropping (147 gm. dry matter to 3,900 gm. moisture-free soil)

SOURCE OF ORGANIC MATTER ADDED	SANDY SOIL			LOAM			CLAY LOAM			AVERAGE PERCENTAGE LOSS FOR ALL THREE SOILS
	Before growth	After growth	Difference	Before growth	After growth	Difference	Before growth	After growth	Difference	
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Cultivated New Jersey peat	5.0	4.3	0.7	9.6	8.6	1.0	9.4	8.9	0.5	9.9
Raw Michigan peat	7.1	4.4	2.7	9.2	8.8	0.4	9.9	8.5	1.4	18.8
Imported peat moss	6.2	3.4	2.8	10.8	9.0	1.8	10.4	8.3	2.1	27.3
Spent mushroom soil	3.6	2.3	1.3	7.5	7.3	0.2	7.2	7.1	0.1	13.4
Well rotted manure	5.6	2.8	2.8	9.7	7.7	2.0	9.0	6.6	2.4	32.4
Control (no organic matter added)	2.6	1.6	1.0	6.8	6.3	0.5	6.5	6.1	0.4	17.4

room soil lost 13.4 per cent, whereas those containing cultivated peat lost only 9.9 per cent. Soil containing raw Michigan peat lost 18.8 per cent, and imported peat moss 27.3 per cent, but even these amounts were less than that noted for manure, 32.4 per cent.

It is dangerous to draw final conclusions from data collected under such a limited range of conditions, but the various substitutes for manure seem to have been somewhat more persistent in the soil than manure itself, and may reasonably be expected to effect the soil to which they have been added fully as long as manure if not to the same degree. Cultivated peat will doubtless prove more persistent than raw peat or peat moss, since it has already undergone considerable decomposition under tillage and probably contains a higher percentage of materials which are resistant to decay.

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to determine the relative effectiveness of five types of organic matter for improving the physical condition of soil for plant growth. Each type of organic matter was added at a light and heavy rate to a sandy soil, a loam, and a clay loam. Certain physical properties of the untreated soils and soil mixtures were measured when the organic matter was first incorporated, and again after German mixed bent grass had been grown for 19 weeks.

Under the system of limited watering and adequate fertilization followed, sandy soil was improved for growth of grass by the addition of all types of organic matter. An analysis of the data on physical properties of the soil mixtures indicates that cultivated New Jersey peat and spent mushroom soil are the most satisfactory types of material for sandy soil, followed in order by raw Michigan peat, manure, and peat moss. Peat moss mixtures with sandy soil were relatively undesirable because of the slowness with which the dry material absorbed water, and the very open structure produced.

The addition of all types of organic matter also improved the loam soil for plant growth, except where large amounts of peat moss were used. The most effective substitutes for manure were cultivated New Jersey peat and raw Michigan peat. Peat moss was satisfactory only when used at the light rate; and spent mushroom soil was the least effective of the organic materials tested, probably because of a relatively high content of silt and clay.

The untreated clay loam soil had a compact structure, and cracked badly in this experiment. The addition of organic matter of any type largely prevented the formation of cracks, modified the physical properties of the soil and increased plant growth. From a consideration of the physical properties of the treated soils and the grass yields produced, fibrous organic materials such as manure and raw Michigan peat seem to be somewhat more suitable amendments than non-fibrous cultivated peat or mushroom soil. The use of peat moss in large quantities with the system of limited watering used, seems undesirable because of the slow absorption of water by the dry material and the exceedingly open structure produced.

Peaty materials which have become thoroughly dry take up moisture very slowly and may produce an undesirable physical condition when incorporated with the soil, particularly if the moisture supply is limited or if water is supplied infrequently in large amounts. The undesirable effect may be intensified in the field if layers of dry peat are placed below the surface of the soil within the root zone, or if the peat layers so placed become very dry.

Loss on ignition determinations made at the beginning and end of the experiment for all treated soils, indicate that the organic matter of manure is more rapidly decomposed and lost than that of any other type of organic matter tested. The organic matter of cultivated peat and mushroom soil was more persistent than that of raw peat or peat moss, probably because the former sub-

stances had already undergone considerable decomposition and contained a higher percentage of compounds resistant to decay.

It is clearly shown that other types of organic matter may be substituted satisfactorily for barnyard manure, if the nutrient deficiencies are corrected by the addition of fertilizer. The choice of the most desirable type of organic matter depends on the properties of the material itself, and the nature of the soil with which it is mixed.

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PLATE 1

THE EFFECT ON PLANT GROWTH OF INCORPORATING VARIOUS TYPES OF ORGANIC MATTER WITH THE SOIL

Fig. 1. Relative values of the three untreated soils used in the experiment, as indicated by plant growth

Pot	Soil class	Yield of grass tops gm.
31	Sandy soil	6.2
32	Loam	10.6
33	Clay loam	9.6

Fig. 2. The effects on plant growth of adding various sources of organic matter to a sandy soil (147 gm. dry matter to 3,900 gm. moisture-free soil)

Pot no.	Material added	Yield of grass tops gm.
6	New Jersey peat	10.3
7	Michigan peat	9.1
8	Imported peat moss	10.6
9	Spent mushroom soil	9.6
10	Well rotted manure	9.3
31	Control (No organic matter added)	6.2

Fig. 3. The effects on plant growth of adding various sources of organic matter to a clay loam soil (147 gm. dry matter to 3,900 gm. moisture-free soil)

Pots removed from soil. Observe cracks formed where no organic matter was added and where spent mushroom soil was added. White line indicates level of the soil.

Pot no.	Material added	Yield of grass tops gm.
26	New Jersey peat	10.8
27	Michigan peat	10.9
28	Imported peat moss	10.3
29	Spent mushroom soil	12.0
30	Well rotted manure	11.7
33	Control (No organic matter added)	9.4

FIG. 1

FIG. 2

FIG. 3

EXCHANGEABLE CATIONS OF THE SOIL AND THE PLANT: I. RELATION OF PLANT TO CERTAIN CATIONS FULLY SATURATING THE SOIL EXCHANGE CAPACITY

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Considerable time and attention are at present paid to questions connected with the condition of the soil which depends upon the composition of its exchangeable cations and with the explanation of the relation of this composition to the chemical, physical, and physico-chemical properties of the soil. However, the relation of the growth of plants and the life and activities of microorganisms to the composition of the exchanged bases in the soil, problems that have no less theoretical interest and at the same time are of considerable practical importance, have received up until the present time, almost no experimental study. Experiments with plants and microörganisms along this line may give us a whole series of very interesting conclusions which can find application to agriculture. Plants and microörganisms form a very sensitive indicator of the changes that take place in soil as a result of a change of its properties and, therefore, also of its exchanged bases. The application of this biological method of investigation of various questions related to the absorbing properties of the soil in the broadest possible sense should not be less fertile in results than the application of chemical and physico-chemical methods. It is quite clear that the broad utilization of this method of investigation together with others that have already become established in soil science is very desirable both in the interest of soil science and agriculture. Our knowledge will thereby become broadened and completed. As an example of the possibility of application of the biological method in soil science, let me point out the question which has interested soil scientists for a long time, namely, can the soil contain exchangeable hydrogen or is the cause of soil acidity always the exchangeable aluminum. As a matter of fact, this question can be answered very easily and simply by the plant: the relation of the plant to soil, treated with aluminum salt until all the exchangeable bases have been replaced, on the one hand, and treated with 0.05 *N* HCl also until all the replaceable bases have been removed, on the other, prove to be, after liming of both, totally different; one cannot say that we are dealing in both cases with exchanged aluminum, and the action of lime upon soil treated with 0.05 *N* HCl solution can be explained only by the presence in it of exchangeable hydrogen.

[1] Translated from the Russian by Dr. S. A. Waksman, New Jersey Agricultural Experiment Station.

The almost total absence of experiments with plants grown in soils artificially saturated with one base or another is explained, of course, by the complexity and comparatively high cost of preparation of soil material needed for such experiments, and the need of certain special facilities for carrying out such experiments.

In my case, for example, the investigations of the biological methods of the questions connected with the absorbing properties of soil, begun in 1911 (3), could bring them to a convenient state only now, the problem outlined 20 years ago not being completed as yet.

Before coming to the fundamental subject of this article, namely, the question of the relation of plants to various cations when each is completely saturating the total exchange capacity of a given soil, I will first consider the marked difference in importance for plant growth of various nutritive exchangeable bases, as brought out in my experiments.

It is known that among the nutritive elements essential for the life of plants, only three—Ca, Mg, and K— are found (or may be found) in the soil in an exchangeable condition; we know further that whatever the quantity of these cations in the soil in an exchangeable condition, these cations are also always found in the soil in a condition not capable of exchange; whereby there is usually present in soil considerably less unexchangeable Ca than exchangeable. (The cultivated horizon of the tchernoziem, with which the first vegetation experiments here described were carried out, contained 1.26 per cent exchangeable CaO and 0.5 per cent unexchangeable.) An inverse relationship is found in the case of Mg and K. (The above horizon contained 0.17 per cent exchangeable and 0.93 per cent unexchangeable and MgO 0.07 per cent exchangeable and 2.04 per cent unexchangeable K_2O.) Soils contain, as a rule, comparatively little exchangeable magnesium, but still a very definite quantity; no soil has been found as yet which has contained no exchangeable magnesium. But this is not true in the case of potassium; the ordinary concentration of exchangeable potassium in soil is a few hundredths of a per cent of K_2O or about 1 mgm. equivalent in 100 gm. of soil. This is such an insignificant quantity that, considering the complexity of replacement of potassium from soil, the complexity of the very method of determination of the quantity of potassium, and, especially the possibility of the presence of traces of potassium in the reagents used, which can give, in the case of the large quantities of reagent used in the determination of exchanged potassium, amounts of potassium of the same order, one should not treat this quantity obtained as one really present in soil. Therefore, until a more sensitive method of determination of exchangeable potassium is developed (this is true, of course, also for the exchanged magnesium and in general for exchanged cations when they are present in soil in very small concentrations) our ideas of its concentration in soil will be more in the nature of guesses.

Why is there then so little exchangeable magnesium and potassium in soil, when the total concentration of these elements in soil is so large? One can

answer this question only in a very general way. It is possible, for example, that as a result of the presence, now or in former times, in the soils of considerable quantities of $CaCO_3$, all the bases present (or which were present) on the surface of the primary particles of soil were replaced by calcium and we could thus not have exchanged potassium (or magnesium), if there were not formed, during the processes of further soil formation, new surfaces accessible to other replacing cations. There is no doubt that such surfaces are being formed and that the inner layers of soil particles may become outer. Such a surface, newly formed, may of course contain, depending on its mineralogical composition, exchangeable potassium and magnesium. It is understood that such a process of new formation of the outer surface must be very slow and, therefore, the quantity of exchangeable potassium and magnesium (and sodium) found in the soil at any given moment may be very little.

Of course, these newly forming outer surfaces must also contain exchangeable cations of calcium, but since the soil contains less unexchangeable calcium than unexchangeable magnesium and potassium, it is natural that, on the average, there will be less exchangeable calcium than exchangeable potassium and magnesium.

Another explanation of this phenomenon is possible. There is no doubt that all soil particles independent of their size, possess exchange capacity, but the intensity of exchange, being directly dependent on the degree of dispersion of the substance in a unit of its volume, will be considerably greater in a colloidal fraction than in a non-colloidal one. If we call the exchange of a colloidal fraction "intensive exchange," we may say that the non-colloidal part of the soil also possesses exchange capacity, but only "extensive." An exchange of a similar order (quantitatively) must also take place in the colloidal soil fraction in respect to the small *residual* quantities of exchangeable cations present, and also in the cations of the newly forming exterior surfaces. The bases calcium, magnesium, and potassium (and sodium) must be on the surface of these larger soil particles; but since the intensely exchangeable calcium forms a large part of the total calcium content of the soil, and the exchangeable magnesium and potassium (and sodium) only a minute part of the total concentration, it is natural to expect on the surface of the larger soil particles relatively more of the exchangeable bases magnesium and potassium than of calcium. At least, there is no doubt that the replacement of exchangeable bases from the soil by treating it for a certain period of time with a salt solution of any desirable cation is never brought to completion. We are replacing only the intensively exchangeable bases and a part of the extensively exchangeable; however, a larger or smaller part of the exchangeable cations of the large fractions plus the exchangeable bases on the newly formed outer surfaces of the soil particles, i.e. in general, the extensively exchangeable cations, remain in the soil. Their total replacement is, probably, a process very prolonged. One may speak of the replacement of exchangeable bases from the soil as only *practically* complete for a given purpose; thus, for example, for the comparative

study of the content of exchangeable bases in soil, it is sufficient at the present time to determine the quantities of exchangeable calcium and magnesium, which are practically replaced from the soil by the given methods, but these methods are still inadequate for the study of phenomena connected with exchangeable potassium. In regard to questions of plant nutrition, we must be able to determine in the soil the quantities of extensively exchangeable bases of calcium and magnesium as well as potassium.

Whatever the causes of the aforementioned phenomenon, however, the very facts of the low content of exchangeable potassium and magnesium in soil, both in absolute and relative concentrations, and just the reverse relation for calcium remain: calcium is present, as an exchangeable base, in the soil in a special position when compared with the other exchangeable soil bases. We will soon see that plants also point to the special position occupied by calcium among the other exchangeable bases necessary for plant life.

As I have mentioned in one of my previous papers (1), I began in 1912 a large vegetation experiment using the cultivated horizon of a tchernoziem rich in humus, artificially saturated completely with calcium, according to my method. The purpose of the experiment was to obtain a soil which reacts strongly to potassium fertilization (natural soils usually react in pot experiments very weakly to potassium, even when large amounts of nitrogen and phosphorus fertilizers are employed), and thus make it possible to study the problems of potassium nutrition by plants not only in water and in sand cultures, but also in soils. The soil thus prepared, containing calcium practically alone of the exchangeable bases, was used for a vegetation experiment carried out in pots (20 by 20 cm.); the same basic fertilizer (0.2 gm. of nitrogen as $NaNO_3$ and 0.2 gm. phosphoric acid as NaH_2PO_4) and varying quantities of potassium sulfate (from 0.05 to 1.0 gm. K_2O per pot) were added. The experiment was carried out with three kinds of plants: oats, mustard, and buckwheat.

All the combinations tested gave for each plant, within the limits of error of pot experimentation, exactly the same yields. The experiment did not yield the results expected. The soil even saturated with calcium did not react to potassium, with the given quantities of nitrogen and phosphorus. This fact alone, however, represents a great interest in connection with questions concerning the rôle of exchangeable nutritive bases in the growth of plants. We will, therefore, consider this experiment and, since, as has been shown, all the pots containing the same plant gave similar yields, we will not report all the extensive data obtained in this experiment, but will limit ourselves to those shown in table 1.

The results show that both the original tchernoziem and the tchernoziem saturated only with calcium had no need of potassium for any of the three plants; since the basic fertilizer did not contain any magnesium and since the original tchernoziem did not need it, the results of the experiment show that the tchernoziem saturated with calcium did not need any magnesium as well.

TABLE 1

Results of vegetative experiment in a tchernoziem saturated with calcium

Crop yield in grams per pot. Basic fertilizer, $NaNO_3$ and NaH_2PO_4

GROUP	SOIL	NO POTASSIUM			0.05 GM. K_2O			0.1 GM. K_2O			0.15 GM. K_2O			0.20 GM. K_2O			0.30 GM. K_2O		
		Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Oats	Original soil	10.2	10.8	21.0	....	....	....	....	....	....	9.7	11.0	20.7	....	....	....	....	....	....
	Soil saturated with calcium	9.3	11.1	20.4	10.2	10.8	21.0	9.8	11.0	20.8	9.6	10.3	19.9	10.0	10.6	20.6	9.9	10.9	20.8
Mustard	Original soil	5.4	13.2	18.6	....	....	....	....	....	....	5.5	13.4	18.9	....	....	....	....	....	....
	Soil saturated with calcium	5.4	13.0	18.4	5.6	12.8	18.4	5.3	12.9	18.2	5.2	12.1	17.3	5.5	12.6	18.1	5.6	12.7	18.3
Buckwheat	Original soil	13.2	12.6	25.8	....	....	....	....	....	....	....	....	....	13.6	12.4	26.0	....	....	....
	Soil saturated with calcium	13.1	12.0	25.1	....	....	....	12.2	13.1	25.3	....	....	....	13.4	11.7	26.1	13.1	12.7	25.8

Similar results were obtained in the experiment, described in the following, carried out in 1929, on the relation of magnesium in a tchernoziem saturated with hydrogen; the same yield of oats was obtained in this experiment, when N, P, K, and $CaCO_3$ (no magnesium added) were added to the soil as in the original tchernoziem with the same fertilization. Experiments without potassium were not carried out again.

Plants are thus able to utilize the elements magnesium and potassium in a soil from which the exchangeable bases of these elements were removed practically completely. When the other nutritive elements were provided, high yields were obtained (10 gm. of oat grain per pot corresponds to about 4 tons per hectar).

Totally different results are obtained concerning the rôle of calcium in plant nutrition: if practically all the exchangeable calcium is removed from the soil and is then replaced by a base, the presence of which does not prevent the development of the plant in one way or another, then, as the experiments here reported show, the plant dies entirely, when no calcium salts are added to the soil.

Thus, for example, the crop of oats in the original tchernoziem with complete fertilizer (N, P, K) was 6 gm. per pot (small pots with 600 gm. of soil). In the soil with complete fertilizer and fully saturated with magnesium, the plants died completely. A yield of 2.5 gm. was obtained, however, when $CaCO_3$ and complete fertilizer were added. The same picture was obtained, as will be seen later, when the soil was saturated with other bases as well.

It is quite clear that in our methods of replacing the exchangeable bases from the soil, the plant in a soil practically freed from exchangeable magnesium and potassium finds in the same soil a source of these elements which are essential for a certain yield; however, in a soil freed from exchangeable calcium, the plant does not find another source of this element in the soil itself.

It is easiest to explain this phenomenon by supposing that by our methods of replacing exchangeable bases we do not replace them completely, in spite of very prolonged washing of the soil with a solution of a salt of the given replacing base. This is actually so, since even after 20 repeated treatments of a soil with a solution of the replacing cation, we cannot remove completely from the soil all the extensively exchangeable bases, whereby, as we have seen, there is reason to suppose that, after such treatment, there are left, of the exchangeable bases in the soil, more magnesium and potassium than calcium; there is left enough of the first two in the soil to allow a normal development of the plants, provided the other nutritive elements are present, to give certain crop yields, while there is left so little calcium as to prevent plant development.

We will now take up the major subject of this paper. Among the numerous questions concerning the exchangeable bases in soil and their relation to plants, the first to be studied was, in my opinion, the reaction to plants of a soil fully saturated with one base or another, either those found naturally in the soil or not. These experiments were begun in 1913; one experiment was carried out

using a tchernoziem saturated with either NH_4, Na, or K. As a result of the complexity of preparation of a soil saturated with these bases and at the same time freed entirely of the salts used for treating the soil to bring about such a saturated condition, and also as a result of the certainty that agricultural plants will not develop in such soils, this experiment was carried out in tumblers containing 200 gm. of soil. Complete fertilizer (N, P, K, and Mg), without and with $CaCO_3$, was added to the soil. The result was that the seeds of all agricultural plants, both in the presence and in the absence of $CaCO_3$, failed to germinate, rotted, and perished. The soil saturated with NH_4, Na, or K was thus found to be a medium totally unsuited for the development of agricultural plants. The causes of this unsuitability are at present, of course, well known to us.

We planned to study further the development of plants in a series of soils having different exchange capacities and saturated to a different degree with these various bases; in respect to the exchangeable NH_4, to study the need of soil in nitrogen fertilization, using such quantities of exchangeable ammonia in soil as are not injurious to plant growth. Such investigations were not only of theoretical but also of practical interest, especially as to our knowledge of alkali soils. This problem could not be carried out, however, and the continuation of our experiments concerning the conditions of growth of plants in soils saturated with one base or another could be undertaken only in 1928.

Soils saturated with the bases Mg, Ba, Mn, Co, Ni, Cu, and H were prepared from a tchernoziem rich in humus. The experiment was carried out in small vessels using 700 gm. of soil. In view of the small quantity of the various soils thus prepared only one plant was employed in this experiment, namely mustard. The soils received either no fertilizer or a complete fertilizer (0.1 gm. N as $NaNO_3$, 0.1 gm. P_2O_5 as NaH_2PO_4, and 0.05 gm. K_2O as K_2SO_4), but no $CaCO_3$. The study of the influence of $CaCO_3$ upon the same soils was postponed to the following year.

The plants yielded a crop (quite a normal one) only in the original tchernoziem. In the case of the soils saturated with each of the foregoing bases, however, the plants either did not germinate or appeared in the form of a few seedlings which soon perished, in spite of repeated planting.

The soils taken from the experiment of 1928 were placed in 1929 in 600-gm. quantities, in pots, and complete fertilizer (in the same quantities as in 1928) was added to all pots containing the original soil. The pots of the remaining soils that were without fertilizer in 1928, received complete fertilizer. The pots that received complete fertilizer in 1928 did not receive any new portion of it since it was not used at all in 1928, but 10-gm. quantities of $CaCO_3$ were added. Oats were the plants used in this experiment.

The following experimental results were obtained (per pot, on the average of two duplicate pots):

Original soil:

Complete fertilizer — total yield 5.7 gm., grain 1.6 gm.

Complete fertilizer + $CaCO_3$ — total yield 5.4 gm., grain 1.7 gm.

The soils saturated with various bases and treated with complete fertilizer but without any $CaCO_3$ gave the same results as in the previous year: either the seed did not germinate at all or the seedlings soon perished.

In the presence of complete fertilizer and $CaCO_3$, the results of last year were repeated in the soils saturated with Ba, Ni, and Co; the plants did not develop at all in these soils and the crop yield was 0; thus, when the three bases completely saturated the full capacity of absorption of a given soil, the oats could not develop, even when the soil was supplied with all nutrients (including calcium).

The soil saturated with Cu, supplied with a complete fertilizer and $CaCO_3$, gave a crop, but of an inconsiderable amount—0.39 gm. of total plant material and 0.05 gm. of grain (5 seeds per pot).

The soil saturated with Mg, supplied with a complete fertilizer and $CaCO_3$, gave a total crop yield of 1.56 gm. and 0.38 gm. of grain.

TABLE 2

Yield of oats on a tchernoziem rich in humus and saturated with various cations

SOIL SATURATED WITH	COMPLETE FERTILIZER		COMPLETE FERTILIZER + $CaCO_3$	
	Total crop yield	Grain	Total crop yield	Grain
	gm.	*gm.*	*gm.*	*gm.*
Original soil	5.9	1.44	5.6	1.20
Mg	0.33	0.01	2.4	0.62
Ca	6.3	1.92	...	....
Sr	5.4	0.8	5.6	0.97
Cd	0	0	0	0
Fe^{++}	0.7	0.14	1.6	0.35
Fe^{+++}	0	0	1.0	0.23
Al	0.24	0	2.6	0.80
H	0.21	0.1	5.7	1.6

The soil saturated with Mn supplied with a complete fertilizer and $CaCO_3$, yielded 1.6 gm. of total crop and 0.18 gm. of grain.

Finally, the soil saturated with hydrogen, supplied with a complete fertilizer and $CaCO_3$, gave a crop yield of oats equivalent to that of the original soil.

These experiments fully confirmed the results obtained in 1912: if practically all the exchangeable calcium is replaced by any other base (in this case by H, Mn, and Mg), the plants will develop only when a calcium salt is introduced into the soil; but if practically all the magnesium in the soil is replaced by another base (in this case by H and Mn), the plant, if it is at all capable of growing in the presence of this saturating base, will develop and give a normal crop yield even without the addition of a magnesium fertilizer.

During 1929, vegetation experiments were carried out in soils saturated with a number of other bases, namely Mg, Ca, Sr, Cd, ferrous and ferric iron, Al, and hydrogen. The experiments were carried out in the same vessels as

in the previous case, with complete fertilizer (N, P, K, Mg), as well as with complete fertilizer and $CaCO_3$. Oats were used as the crop. The yields thus obtained are given (the average of two parallel pots) in table 2.

In this experiment as well, the soils saturated with most of the bases studied, in the absence of $CaCO_3$ gave either no plant growth at all (Cd and Fe^{+++}) or gave very limited crop yields (Mg, Al, H). A higher crop yield was obtained, in the absence of $CaCO_3$, in the soil saturated with ferrous iron (it is possible that the exchangeable calcium was not completely removed from the soil). A high crop yield was obtained, in the absence of $CaCO_3$, in the soil saturated with calcium (about the same as in the original soil). The reason for this is quite clear. But quite unexpectedly the crop yield on the soil saturated with Sr, in the absence of $CaCO_3$, was about the same as in the original soil or as in the soil saturated with Ca (considerably less grain). If we consider the data for all the other exchangeable bases here studied, we must recognize that in the soil saturated with strontium, the plants can do without available calcium, a phenomenon not taking place in the case of the other cations tested; the conclusion suggests itself that strontium may to a certain extent take the place of calcium for plant growth.

The introduction into the soil used in this experiment of $CaCO_3$ in addition to N, P, K, and Mg has markedly changed the general picture. Of the eight soils saturated with various bases (namely Mg, Ca, Sr, Cd, Fe^{++}, Fe^{+++}, Al, and H) a crop yield was obtained only in the case of calcium and strontium and possibly also of ferrous iron. In the same soils treated with $CaCO_3$ only the soil saturated with cadmium gave no crop; cadmium saturated the base exchange of the soil and killed the oats entirely. The plants grew on all the other soils, giving a crop of varying magnitude. A crop of about the same magnitude as on the original soil was given by the soil saturated with hydrogen (as in the previous experiment) and by the soil saturated with strontium. In the case of all the other exchangeable bases, the plants grew but gave a considerably lower yield: in the case of the soil saturated with Mg or Al, the crop was about half the size of that in the original soil, while the ferrous and ferric iron saturated soils gave even lower yields.

We may consider it definitely established at the present time that various physical and chemical soil properties, including not only those of the solid phase but also of the liquid and gaseous phases, are closely related to the composition of the bases saturating the exchange capacity of the soil. We now know that of the various elements entering, in appreciable quantities, into the composition of the soil (Na, K, Mg, Ca, Al, Fe, H, as well as Mn, NH_4, and Li), calcium occupies, as an exchangeable base, a special rôle in the life of the soil. First, it is usually present in soils (at least in those which are not too much destroyed) in considerably larger quantities than all the afore-enumerated metals, in the form of exchangeable bases. Secondly, when calcium saturates or almost saturates the exchange capacity of the soil, there are created in the soil conditions most favorable for supporting in the soil solution a reaction close to

neutrality; the elements Li, NH_4, Na, K, and partly Mg, as exchange bases, bring about a more alkaline reaction, whereas Mn, Al, Fe, and H bring about an acid reaction. Third, the exchange calcium creates in the soil special physical conditions, as a result of which a mutual relation is established between the aqueous and gaseous portions of the soil which is most favorable, in a given soil and given climatic conditions, for the growth of most higher plants and aerobic microörganisms. In the case of all the cations, as exchangeable bases, afore-enumerated, this relation is less favorable. Magnesium is nearest to calcium in all these respects.

As a result of the afore-reported vegetation experiments in soils fully saturated with one of the following 16 bases: H, NH_4, Na, K, Mg, Ca, Sr, Cd, Ba, Mn, Fe^{++}, Co, Ni, Cu, Al, Fe^{+++}, we find that the plant as well points to the very special position of exchangeable calcium among all the bases tested.

We have seen that, on the one hand, in a soil not containing exchangeable calcium, the plant does not develop at all, if some calcium salt is not added to the soil to serve as a source of calcium for the plant; that portion of calcium of the soil which is not exchangeable (at least intensively), as opposed to the unexchangeable magnesium and potassium, cannot be assimilated by plants in sufficient quantities required for their growth; on the other hand, the experiments have shown that this base may fully saturate the exchange capacity of the soil and the plant will develop in such soil, as measured by crop yield, as well as in a natural soil which contains, in addition to exchangeable calcium, exchangeable magnesium.

Of all the 16 cations tested in saturating fully the exchange capacity of the soil, only one other, namely strontium, which is very close to calcium in its properties, proved to be closely related to calcium also in its action on plants. In the soil saturated with this base, i.e. not containing any exchangeable calcium, the oats develop almost as well as in the soil containing exchangeable calcium. The total yield of oats in this soil was almost the same as that of the original tchernoziem and that of the tchernoziem saturated with calcium, but the grain yield was less. Thus, strontium-saturating a soil completely, on the one hand, failed to injure the plant, just as when the soil was saturated with calcium, and, on the other hand, strontium seemed to have replaced calcium as a nutritive element for plant growth.

All the remaining elements saturating completely the exchange capacity of the soil and thus removing the available calcium necessary for plant nutrition produced soils on which the plant, if it developed at all, grew only when $CaCO_3$ was added to the soil. Of these elements, let us consider first the hydrogen ion.

The experiment shows that in a soil fully saturated with H, the oats did not develop at all, in the absence of $CaCO_3$. Two causes prevented their growth: the absence in such a soil of available calcium and the acid reaction. The introduction of $CaCO_3$ removed these causes, and the soil gave then as large a yield as the original tchernoziem or the tchernoziem saturated entirely with calcium. The introduction into such soil of $CaSO_4$ in place of $CaCO_3$ showed

that the growth of oats was prevented not only by the absence of sufficient calcium available for plant growth, but also by the unsaturated condition of the soil with bases (to be more exact, those free acids which were formed in such soil as a result of exchange of the bases of the salts in the soil solution by the hydrogen ion of the unsaturated soil). The results were as follows:

(Soil fully saturated with hydrogen)

Complete fertilizer	Total crop yield	Grain
	gm.	*gm.*
$-CaCO_3$	0.21	0.10
$+CaSO_4$	0.24	0.02
$+CaCO_3$	5.70	1.60

Of the remaining bases studied, all, i.e. NH_4, Na, K, Mg, Cd, Ba, Mn, Ni, Co, Cu, Fe^{++}, Fe^{+++}, and Al, when they saturated completely the exchange capacity of the soil, in the absence of $CaCO_3$, brought about the complete death of the oats. In the presence of $CaCO_3$ in soil saturated with some of these bases; namely, NH_4, Na, K, Cd, Ba, Ni, Co, Cu, the oats also perished; the soil saturated with these bases gained chemical properties[2] which prevented plant development even in the presence of all the elements necessary for growth. It seems that one deals here with those toxic products which are produced in the soil solution of these soils. These bases, which enter the soil solution, as a result of their replacement from the soil by the cations of the nutrient salts added or by the hydrogen ion of water form such products. It is evident therefore that in the case of the exchangeable NH_4, Na, and K, the toxicity is brought about not by these bases themselves but by the free hydroxyl ions liberated in their presence. The remaining bases (Cd, Ba, Ni, Co, and Cu) seem to destroy the plant by being directly toxic, and not as a result of the formation in the soil solution of a reaction unfavorable for plant growth; the reaction can be changed only to a limited extent by the introduction of these bases into the soil, and even then it will be toward acidity, which, under the conditions of our experiment (the presence of $CaCO_3$), cannot have an injurious effect upon plant growth.

Finally, in the soils saturated with one of the following bases: Mg, Mn, Fe^{++}, Fe^{+++}, Al, the oats perished in the absence of $CaCO_3$, but grew in the presence of this compound, giving, however a lower crop yield. Although the original tchernoziem, saturated with calcium alone, gave about 6 gm. of the crop per pot, the soils saturated with these bases + $CaCO_3$ gave the following yields:

	gm.
Mg	2.4
Al	2.6
Mn	1.6
Fe^{++}	1.6
Fe^{+++}	1.0

[2] Under the conditions of our experiments with the soils saturated with bases, the special physical properties of these soils could not play any important part in the death of the plants.

These bases, when fully saturating the exchange capacity of the soil, are thus found to be also toxic to plants, although to a less extent than reported previously. Of these bases, magnesium and aluminum are less injurious than manganese or the oxides of iron.

The foregoing considerations point to the special rôle of exchangeable calcium in the life of plants. *Of all the cations investigated, as exchangeable bases in soil, only calcium (and evidently to the same extent, strontium) creates in the soil, when fully saturating its exchange capacity, conditions most favorable for plant life.*

The question concerning the influence of various combinations in the composition of exchangeable bases in soil upon plant growth was not touched upon at all in the aforementioned experiments. The fact, for example, that barium, when fully saturating the base exchange capacity of the soil, destroys the vegetation entirely, cannot as yet lead us to conclusions concerning the influence of this base upon plants when it saturates in the soil only a part of its base exchange capacity while the remaining part is saturated by calcium. It is quite possible to admit, if not in respect to barium, at least in respect to some of the other toxic bases, that when present in very small amounts in the soil absorbing complex, they will not only be uninjurious to plant growth, but may prove to be stimulants, as found in the case of salts of certain elements. The great interest and the possibly considerable practical importance of the further continuation of these experiments in greater detail thus become evident.

An attempt was made in this connection to study the influence of various relations between the exchangeable calcium and magnesium in soil upon plant growth. Sixteen samples of soil were prepared from the tchernoziem with varying ratios of exchangeable calcium and magnesium. These soils were used in 1929 for a vegetation experiment with oats carried out at the Nossov Agricultural Experiment Station. Unfortunately, because of unfavorable conditions, the checks in the duplicate pots were so inadequate that it was impossible to draw any conclusions from the crop yields in the small pots. However, the development of the oats in this experiment has shown clearly that within the limits of minimum content of absorbed magnesium in the original tchernoziem and the maximum in the soil saturated with magnesium, there were pots with an optimum plant development. It is evident that a certain increase of the quantity of exchangeable magnesium at the expense of exchangeable calcium has exerted a favorable effect upon the oats in the tchernoziem under investigation. This question concerning the exchangeable magnesium is doubtless of a very practical interest, since it is connected, for example, with the question of the amount of magnesium permissible in the lime used for liming of soil. It is possible that the special care which some persons exert in this connection may prove to be unnecessary. It is interesting to note that, according to the data obtained in this experiment (data which are, however, not fully dependable), the oats were not affected injuriously when a large part of the exchangeable calcium of the soil was replaced by magnesium. These experiments will be repeated.

Let me call attention further to the fact that in respect to exchangeable sodium, which when fully saturating makes the soil, totally unsuitable for cultivation, theoretical considerations (2) definitely speak in favor of the presence of a small quantity of it in a tchernoziem, creating at least favorable conditions for nitrogen nutrition. This was confirmed by a small experiment carried out a few years ago at the Nossov Agricultural Experiment Station. This experiment will be repeated on a larger scale.

CONCLUSIONS

The growth of oats and, in some cases, of mustard and buckwheat in a tchernoziem rich in humus was studied; the exchange capacity of this soil was saturated with one of the following bases: H, NH_4, Na, K, Mg, Ca, Sr, Cd, Ba, Mn, Fe^{++}, Co, Ni, Cu, Al, Fe^{+++}.

The crops gave the same yield as in the original tchernoziem only in the soil saturated with calcium. The soil saturated with strontium gave almost as large a yield as the original soil or the soil saturated with calcium; this soil needed no calcium fertilization.

The plants did not grow at all in the soils saturated with each of the remaining bases, both without fertilization and with nitrogen and phosphorus fertilization. When, however, $CaCO_3$ was added to the soil, in addition to nitrogen and phosphorus, a normal crop, similar to that in the original soil, was obtained only in the soil saturated with H; in the soils saturated with Mg, Mn, Fe^{++}, Al, Fe^{+++}, a crop was obtained, to a smaller extent, however, than in the original tchernoziem. The plants perished entirely in the soils saturated with all the other bases (NH_4, Na, K, Cd, Ba, Co, Ni, Cu), both in the presence and absence of $CaCO_3$.

After the practically complete replacement from the soil of exchangeable calcium, the plants require for their development the introduction into the soil of calcium fertilization, without which they do not grow at all; they are unable to utilize the unexchangeable calcium of the soil.

After the practically complete replacement from the soil of Mg and K, plants are able to develop and give a more or less normal yield even without the introduction into the soil of magnesium and potassium fertilizers; the plants are able to utilize the unexchangeable magnesium and potassium of the soil.

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AN IMPROVED SOIL SAMPLING TUBE

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During the past few years certain investigations in progress here at the Oklahoma Agricultural Experiment Station have required that a considerable number of soil moisture samples be taken. A soil auger has been used for most of these studies but there are many objections to a soil auger, some of which are as follows:

Contamination of the deeper samples with soil from the wall of hole due to friction which occurs as the auger is withdrawn, especially when soils are wet.
Slow penetration in case of dry or very compact soils.
Difficulty of removing soil from hole when it is dry or very sandy.

Although the last objection can be overcome by using an auger with a sleeve as recommended by Tinsley and Vernon (9), the first two objections are not easily remedied.

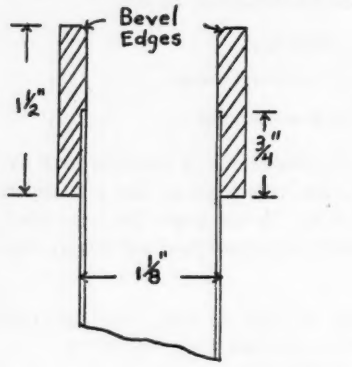
King (3) has designed a soil sampling tube which has been used rather extensively by many investigators. Modifications of this tube are described by Kopp (4) and Veihmeyer (10). Other methods of obtaining soil samples have been used by Stevenson (7), Powell (6), and Green (2), and Neller (5), but they were not designed to obtain samples for soil moisture studies and are of use for taking only shallow samples.

The chief objections encountered in the use of soil sampling tubes are that they are very difficult to remove from many soils because of two factors, as follows:

Friction between expanded portion of tube and soil face
Suction developed in moist soils as tube is raised

In order to overcome these two difficulties several different tubes were designed and tested. Plate 1 shows a soil sampling tube on the left which is used by the staff of the Bureau of Chemistry and Soils, U. S. Department of Agriculture. In the center are two driving hammers and on the right are three sampling tubes designed to reduce the friction between the tube and the soil by making a series of tubes, the larger one for surface layers of soil and the smaller ones for the deeper horizons which are sampled. Veihmeyer (10) suggests decreasing the outside diameter of the cutting point on the tubes used to take the deeper samples; however, this does not overcome the problem of reducing the friction

which arises between the hole and the tube and which is often increased as a result of loose material falling in above the expanded portion at the lower end, and also it does not reduce the suction which develops when the tubes are used in moist soils. Under favorable conditions the tubes shown on the



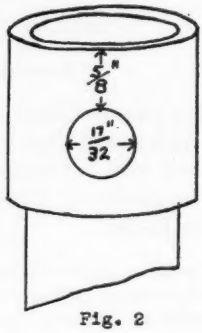


Fig. 2

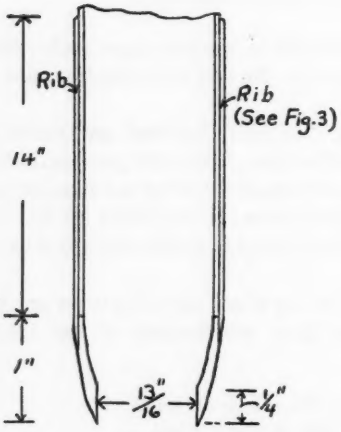


Fig. 1

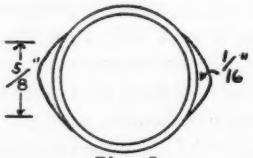


Fig. 3

FIG. 1. LONGITUDINAL SECTION OF SOIL SAMPLING TUBE MADE FROM 14-GAUGE SEAMLESS STEEL TUBING

FIG. 2. COLLAR OF SOIL SAMPLING TUBE SHOWING HOLE IN WHICH STEEL ROD IS INSERTED

FIG. 3. CROSS SECTION OF RIBBED PORTION OF SOIL SAMPLING TUBE

left of plate 1 can be pulled from the soil without a jack (8) and consequently this reduces the amount of time required to remove the sample. However the use of a jack under any condition is objectionable and any procedure which will reduce its use to a minimum would be desirable.

Further studies on the design of a tube which would overcome the problem of friction between portions of the tube and the soil wall and also reduce the suction force encountered when the tube is driven into moist or wet soil resulted in the use of a rib attached to the side of the tube which increases the size of the hole when the tube is given a complete turn after it is driven to the desired depth. Also the tendency to produce a partial vacuum at the bottom of the hole is reduced because the tube does not have an expanded portion at the lower end, and when the ribs are moved, air can pass immediately into the bottom of the hole. Later investigations indicated that two ribs placed on opposite sides of the tube were better than one rib placed on the tube. A steel rod inserted through a hole in the collar of the tube has many advantages over handles welded to the collar of the tube. A design of the tube as recommended is shown in figures 1, 2, and 3. A suitable driving hammer can be made from a piece of steel shafting about 3 inches in diameter and 8 inches long. A hole should be bored in the center of each end of the shaft and steel rods about five-eighths of an inch in diameter and 18 inches long can be threaded and screwed into the holes.

For surface sampling in ordinary soils a 3-foot zone can be sampled with one tube of proper length. In very compact or dry soils only two 1-foot samples can be removed conveniently with each tube. For sampling soils to a depth of 6 feet, three tubes are recommended as follows:

Tube No. 1, 4½ feet long, 1⅛ inch in diameter
Tube No. 2, 5½ feet long, 1 inch in diameter
Tube No. 3, 7½ feet long, ⅞ inch in diameter

Tube no. 2 is used only when very unfavorable conditions are encountered.

The tubes should be constructed of 14-gauge cold rolled seamless steel tubing and the collar and cutting point should be case hardened so that they will not batter from continued use. In case longer tubes are made, heavier gauge tubing should be used. The collar should be brazed to the tube but the steel ribs should be welded because steel takes a better polish than the copper alloy and consequently it does not adhere to the soil as readily as the brazed surface and the tubes can be turned in the hole and extracted from the soil with less energy than when the ribs are attached with brass.

Oiling the tubes will help materially in reducing the amount of energy required to pull them from the soil, when sticky soil is encountered.

In case loose soil falls into the hole it can be discarded when the tube is inverted and only the solid core saved for the sample.

When tubes of different diameters are used, the cutting edge should be about one-tenth of an inch smaller than the inside diameter of the tube. The cutting edge should be turned from a piece of steel shafting and welded to one end of the tube. In case tubes of larger diameter are constructed it may be necessary to increase the thickness of the ribs.

A steel rod one-half inch in diameter and 24 inches long is used to turn the

tubes after they are driven into the soil and serves as a handle by which they can be pulled.

For deep sampling an auger probably can be used to better advantage than tubes. Alway, McDole, and Trumbull (1) have recommended the equipment needed for both shallow and deep samples; however in tests made at this station a 4-inch post auger is preferred to a small auger for digging deep holes. Many holes have been dug to a depth of 22 feet at this station and less than one hour has been required to take samples from individual holes even when very compact, sticky soils are encountered.

In case of stony soils the large auger is also preferable because samples can often be obtained with it when they cannot be taken with either the soil tube or the small auger.

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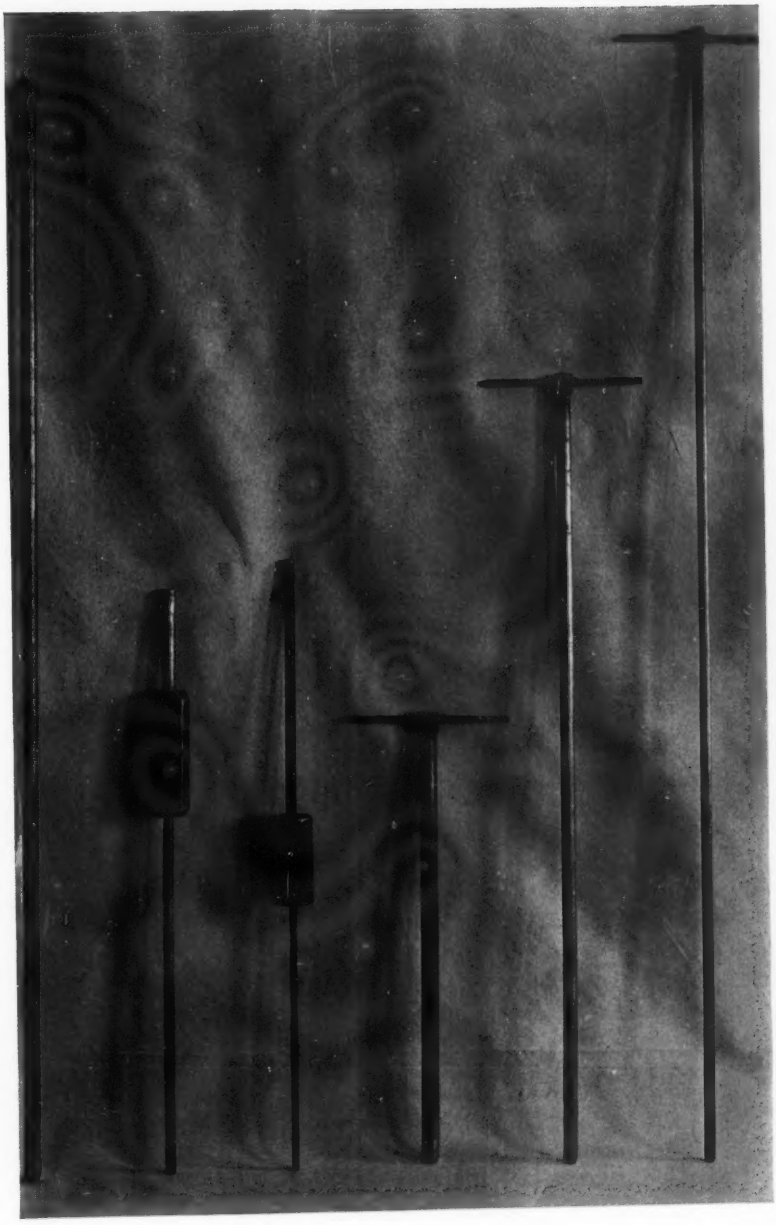
PLATE 1

Soil Sampling Tubes and Hammers Used in This Investigation

IMPROVED SOIL SAMPLING TUBE

HORACE J. HARPER

PLATE 1



BOOK REVIEW

The Physical Properties of the Soil. By B. A. KEEN. Longmans, Green and Company, Ltd., London, 1931. Pp. vi + 380, figs. 93.

Dr. Keen is to be congratulated for the timely appearance of his book on the physical properties of the soil. He has exhibited the rare quality of a thorough scholar and the ability of a trained physicist in the preparation of a text that is a delight to read and a source of inspiration to serious investigators and students in this important field of applied physics.

The book contains much that has been produced by Rothamsted workers in recent years and a coherent and comprehensive survey of an extensive literature on a subject involving great complexity. Students who have a mathematical training will succeed best in the interpretation of certain parts of the text, although much of it is very thoroughly intelligible to students less fortunate. In fact, many farmers would enjoy and profit by reading such chapters as the historical introduction, the chapter on cultivation implements, and numerous paragraphs throughout the text. The discovery, which seems to be due to Dr. Keen and his associates, of a more or less permanent pattern of resistance to the plow on a visually uniform field is a challenge to the admiration and an explanation of a heretofore unexplained variability in random samples. One can scarcely fail to marvel not only at the significance of the isodyne record but at the mechanical device itself which rides modestly along on the plow and leaves a record of one of the most significant of all physical properties—the friability of the soil.

Certain phases of the science, such as the theory of mechanical analysis, the laws of movement of moisture, the elastic and plastic properties and processes, and thermal adjustments, seem to be crystallizing into permanent form. Colloidal chemistry and colloidal physics, such as they are, and the recent work with the exchangeable bases, have also been given careful consideration and the discussion will prove profitable and interesting. We shall hope with Dr. Keen, however, that the future will bring new enlightenment in these somewhat elusive aspects of soil physics.

The author has made a successful effort to give due consideration and recognition to contributions from various sources, and American investigators come in for much credit for the part they have played.

The book will serve a useful purpose as a text for agricultural students and will stimulate prospective young investigators to prepare themselves to wrestle with mathematics and physics as a schoolmaster for service in this basic industrial activity. This book will not be overlooked in America.

WILLARD GARDNER.

ANNOUNCEMENT

The price of Proceedings of the First International Congress of Soil Science will be increased on July 1, 1931, to $5.50 a set to members of the society in the United States and to $6.50 a set to members in foreign countries, according to a recent announcement of the Executive Committee of the American Organizing Committee of the Congress. This additional charge is necessary to take care of transportation cost.